CREW RESOURCE MANAGEMENT TRAINING AND AIRLINE ACCIDENT PREVENTION

Assaad Farah

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ABSTRACT

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Human resource training in the airline industry is of cardinal importance for aviation safety. Pilots are the key players in this industry and human resource training dedicated at reducing pilot error plays a significant role in decreasing a large number of aircraft mishaps. Crew Resource Management is the elite training method that deals with human error reduction within the aviation industry. This study proposes that the evolution of Crew Resource Management training helps reducing particular types of airline pilot errors. Archival data on aircraft mishaps in the United States taken from the National Transportation Safety Board is used in the evaluation of the aforementioned training development.

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Dedications

I dedicate this work to my parents who supported me in all possible ways throughout my university years. I also dedicate this thesis to Capt. S. Geha for all the moral and technical help he provided me.

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OVERVIEW OF PILOT SKILLS AND AVIATION TRAINING

The most prominent safety concern amongst airline personnel and passengers is certainly aircraft accidents (Spangler, 2002). The word, "Accident", is defined by today's dictionaries as an unfortunate event that is caused by unintentional acts or factors due to chance (The New Oxford American Dictionary, 2001). An accident that is not caused by a feature entirely related to chance is said to be usually triggered by an error. Identifying, recognizing, and hence, decreasing this error is cardinal in the development of accident prevention work. However, although technical errors are relatively easy to define and correct, human error is a more challenging element to understand and resolve. The design of training programs that deal with the reduction of human related types of error is essential in workplaces where human error can have crucial consequences. Eventually, the evaluation of these programs is required, in order to assure safety.

The airline industry functions under intricate and high-risk situations, and, accident prevention is at the core of airline operations. Perhaps one of the most effective and yet, complex means to prevent aircraft mishaps, is professional pilot training. Indeed, pilot skills required and enhanced through training are multi-faceted, and, do not rely solely on the knowledge or ability to fly an aircraft. Rather, every facet of a pilot's job has to be evaluated, analyzed, and, developed to fully maximize the performance of this key player within the aviation industry.

This paper will closely scrutinize errors behind aircraft accidents and incidents, in order to analyze the evolution of pilot human resource training in relation with the reduction of particular types of errors. For this purpose, the philosophy of training in general will be exhibited, and, a close look at the skills required from professional pilots will be examined, along with a thorough inspection of the aviation training history. Moreover, since human error is at the core of this analysis, the paper will define human error and will expand on it in the aviation industry. Subsequent to that, the contemporary pilot human error-reduction training program development will be meticulously studied, evaluated and analyzed. This being said, standpoints on training are presented hereunder.

Perspective of Training

Organizations refer to training as the methodical and systematic acquirement of skills, attitudes and rules, which outcome helps improving performance in the work environment (Goldstein, Macey, & Prien, 1981). The first step in designing a training program is to conduct a job analysis, in order to assess the needs required for the job, and, eventually establish the factors that should be emphasized in the program. Means to improve performance in factors that already existed in previous job analysis and training programs can then be further developed. Moreover, factors that appeared for the first time in the job analysis, and that were labeled as 'relevant' or 'highly relevant' to the work, must be integrated and enhanced in the training program for that particular job (Goldstein, 1986).

Indeed, with the increase in technology and automation, organizations are operating under more complex technological environments. The augmented automation amplifies the demands on the human being performing a certain task and, hence leads to important changes in the results of the new job analysis. In fact, professionals in highly technological environments are no longer dealing with straightforward procedural and conventional tasks, rather, people are required to make judgments, conclusions, diagnoses and decisions, sometimes under high-pressure situations (Goldstein, 1986). Campbell (1988) and Goldstein (1986), state that in an altering technological environment it is imperative to understand learning abilities along with the types of aptitudes required at diverse stages in the learning process. Schneider and Konz (1988), reveal that in a new training program that is designed as a result of a technology shift, the process of transmitting information to trainees must be extensively examined and tested in order to assure that the trainee understand the objective of the training as well as its importance. In these types of training, the first challenge is to create participants' awareness of the need and objective of learning. Unfortunately, in some instances, managers arrange training programs and employees are simply asked to attend them. In some cases, these programs are seen as a pleasant relief from every day work or as a sign of the company's interest. Nonetheless, in many other situations, employees perceive training programs as a burden, an insult, or a waste of time. Eventually, they attend the courses with indifference, resistance, and sometimes hostility (Friedman & Yarbrough, 1985). The latter, applies to professionals that have been employed in a job for a long period of time, especially if their profession requires unique knowledge, skills and abilities. The job is their identity, and training means that they lack proficiency in what they do best. They perceive the need for change as threatening, and, might believe that what they have been doing all these years was insufficient (Chao, & Kozolowski, 1986).

Highly skilled employees require complex training programs, which use techniques that not only are appealing to the trainees but also are effective in enhancing their job performance. In general, these types of jobs are technical in nature and involve judgment and decision-making. If the environments in which these jobs are being performed have changed, this means that, the familiar way through which the work used to be conducted in is no more adequate to assure efficiency and sometimes safety (for example: physicians and pilots) (Hicks, & Klimoski, 1987). In this case, to optimize performance through training, participants must first have a clear and systematic understanding of the option they are to learn. Second, they must know when the option should be used and how they should carry it out. Third, they must identify how to put the training into practice in their every day complex tasks. This is done through the development of work procedures and teaching those procedures not only in informative lectures, but also in simulation of work situations (Friedman, & Yarbrough, 1985).

A simulation is a practice situation system, which reproduces as likely as possible chosen constituents of real-life work settings, so that trainees can experience making and carrying out choices involving those components (Goldstein, 1986). Simulations are often referred to as ' games', and, in some cases as 'structured exercises'. In a simulation, trainees become actively engaged in performing work functions during the exercise. Unlike the other methods, simulation training amplifies reality more, runs for a longer period of time, allows versatility among trainees, and gives more freedom for the participants to make individual choices and inferences while completing the exercise (Friedman, & Yarbrough, 1985).

Even though current research on simulation training is scattered and insufficient, many studies agree that simulations are enjoyable, inspiring, and related to the actual job (Goldstein, 1986). Simulations offer a welcome break from more inert training methods particularly in long training sessions. On the other hand, some researchers say that when simulations create a lighthearted mood among trainees, this, could be disadvantageous with regard to the effectiveness of the program. This inclination must be offset by explaining thoroughly why the simulation exercise is being used and by emphasizing on the relationship between the exercise and real-time job situations (Friedman, & Yarbrough, 1985).

Despite the fact that simulations are time consuming and more expensive than other training methods, they however offer a unique chance to train employees on situations that could only be taught in on-job-training, which can be more expensive, requires even more time and might have safety constraints (Goldstein, 1986). Simulation centers the attention of participants on particular dimensions of a job, eventually, removing distractions that can arise in other training methods or in real-life circumstances. Lastly, when a simulation exercise ends, trainees have the chance to undergo a self-evaluation based on different criteria encountered in the simulation (Friedman, & Yarbrough, 1985).

This being said, and after emphasizing the importance of job analysis prior to the design of a training program, it is crucial to understand the job of an airline pilot, in order to understand the most pressing factors that should be dealt with in contemporary pilot training programs.

Pilot Job Analysis

Understanding the job of highly skilled employees is vital in the design and development of successful training programs (Goldstein, 1986). Goeters, Maschkle, & Klamm (1998) from the German Department of Aviation and Space Psychology (DLR), conducted a job analysis on the work of a professional pilot. Their findings reveal that the most vital factors influencing the success of airline pilots, do not simply lie in cognitive and psychomotor elements, but rather go beyond and encompass personality issues as well.

The DLR results of the job analysis for professional pilots, represented in Appendix A, reveal that factors that are imperative to the work of an airline pilot are: stress resistance, cooperation, communication, decision-making, situation awareness, leadership, self-awareness, resistance to premature judgment, behavior flexibility, resilience, assertiveness and motivation. These factors demonstrate the need for building an effective training program dedicated at enhancing interactive and social skills for pilots in the airline industry. Indeed, the next section shows the evolution of pilot training from purely technical curriculums to programs that mingle technological courses with human error avoidance principles.

Aviation Training History

Aviation training programs are one of the most complex and specific education curriculums offered to professionals. They involve various elements related to human factors, psychology and engineering. The evolution of aviation training since the early 1940s, has developed with one core value in its vision: safety first. In the early ages of aviation, pilots were trained with the belief that a severe mechanical dysfunction was highly probable each time they took off the ground. In fact, the engines produced in the late 1930s and early 1940s were so unreliable, that, their failure rate was compared to that of tossing a coin (Spangler, 2002). During this period, the main focus of instructors lay on engine breakdown, hence, pilot students were primarily trained on 'forced landing' (Fried, 2000). Furthermore, prior to the 1970s, due to the various technical difficulties encountered by pilots, the main focus of aviation training still revolved around technical failure. Since then, the evolution of technology and science has caused the probability of losing an engine to become increasingly remote. In fact, aircraft production flourished during this period and led to today's engines having a probability of failure equal to 0.002% (Russell Short, & UNSW, 1999). Moreover, with the propagation in commercial aircraft automated flight controls, the latter techniques used for decades in training professional pilots have evolved significantly. As an example, the earlier philosophies that used to focus on manual control of the airplane are now redeveloped in parallel with simulator training and courses that cater to today's automated airplanes. Today's cockpits, characterized by microprocessors and flat-panel displays, no longer have the need for the traditional skills formerly required by pilots. In turn, with this increased automation, flight training schools have discovered that pilots need to now spend more time on avionics[1] than ever before. An example of this, is the introduction of the first Flight Management System (FMS) in the early 1970s; a black box that plays the role of a third crewmember. Capable of controlling practically every aspect of flight,

[1] Systems that deal with cockpit to ground communication, aircraft positioning, autopilot, collision avoidance instruments, warning instruments, etc.

from climb and cruise, to descent and approach, this is the perfect complement for today's aircrafts, which are flown by a Pilot and a Co-Pilot. In turn, with the introduction of the FMS, the development of a training program, which incorporates its manipulation and understanding, was required. Training techniques evolved to adapt to "the times" and, began offering technical training with the aid of flight simulators (Pope, 2001).

Consequently, augmented automation in aircrafts led aerospace agencies to rethink their curriculum and training techniques. Realizing, that teaching a pilot "how to fly" was no longer sufficient to meet the industry safety demands and requirements, new strategies and programs were implemented to cater to this new philosophy. Incorporated in this revolution of training perspective came the understanding of the importance and impact of human error on accident prevention. Indeed, in 1979, the National Aeronautics and Space Administration (NASA), created a workshop called 'Resource Management on the Flight Deck' (Cooper, 1980). In this practicum, NASA presents findings that reveal the pivotal role of pilot error or 'human error' in air accidents or incidents. The main focus revolves around training pilots in the reduction of crew error, and, optimizing human resources and performance in the cockpit (Helmreich, 1996). This NASA initiative opened the door to a whole new type of aviation training that not only deals with technical issues but also addresses human error in relation to aircraft mishaps. Towards this end, it is essential to define human error in its complexity and repercussions within the aviation environment.

HUMAN ERROR IN AVIATION

In light of research findings that prove that over 70% of aircraft accidents and incidents are linked directly to human error, NASA's concern on human behavior in the cockpit has been justified (Wiegmann, & Shappell, 2001). However, some people would tend to say that the aviation accident rate (1.2 accident per million departure) is extremely low in comparison with other mass transportation means[2] (McVenes, 2001). Nonetheless, with the projected increase in air travel for the next decade (10%/year in Asia, 4.6%/year in Europe and 4%/year in the U.S.)[3], we need to further increase the focus on human error in order to decrease the accident rate in the future (Air Transport Action Group, 2000). The aircraft accident rate has major consequences on the airline industry since it could have a destructive impact, not only on loss of lives and money, but, also on travelers' perception and confidence. In fact, a survey conducted by Langer (2000) revealed that 29% of the sample asked, 1001 American adults, believed that the most recent airline accidents at that time (e.g. Egypt Air flight 990, TWA flight 800 and Swissair flight 111) meant that air travel was getting less safe. These facts draw light on the necessity to recognize and study human error, in order to minimize it and, in turn reduce aircraft accident frequency.

Human Error Definition

Understanding human error is vital in the design of a training program that aims at reducing human-related types of errors in the workplace. Many definitions and classifications exist for human error. Petersen (1982), wrote that human error

[2] American commercial airline flights are about 22 times safer than car travel (Norris, 2002).
[3] These forecasts were conducted prior to the regrettable events of September 11 2001.

consists of many significant deviations from a previously established, required, or, expected standard of human performance, which results in unwanted or undesirable time delay, difficulty, trouble, incident, malfunction, or failure. Bogner (1994), in an article dealing with human error in medicine (a field where human error could be disastrous) defines 'human error' as "an inappropriate action, or intention to act, given a goal and the context in which one is trying to reach that goal." Reason (1990), in a paper on human error in manufacturing, classified human error as a mistake, a lapse or a slip. For Reason (1990), a 'mistake' is a deficiency or failure in the judgmental and/or inferential processes involved in the selection of an objective or in the specification of the means to achieve it, irrespective of whether or not the actions directed by the decision-scheme run according to plan. On the other hand, a 'lapse' is a memory failure and a 'slip' is a failure that is the result of a good plan but poor execution. In this paper, all of the above definitions relate to the context in which human error is used in this research. However, it is important to notice that when human error is examined, the author will make no distinction between human error, which lead to an accident (or incident), and human error whose outcome did not lead to an accident or any undesirable consequence. After defining human error, it is essential to examine the factors that cause this error to occur in technological environments.

Factors that Induce Human Error

Many organizational systems are designed in a way that allows room for human error. What is meant by "system" here, is any group of people, equipment, and procedures in an organization. Even though errors are related to the action of an individual, there are sometimes external factors or events that induce or facilitate the occurrence of the error. Human error is commonly caused or triggered by the individual, the environment, or, the interaction between the human and the machine/technology. To better understand human error, each contributing factor has to be closely examined.

Human-Machine Interaction and the Work Environment. Among factors leading to increased human error is the incessant interaction humans have with machines and, the environment in which the individual is performing the job. These factors are of great importance in aviation, however, in this paper, the interest is directed towards the 'individual' factors behind pilot error. Nonetheless, its is vital to draw an overall picture of the factors that can affect a highly skilful technology worker error (such as a pilot), in order to position the individual's effect on error within that framework.

It is interesting to mention here what Casey (1993) said with regards to the interaction between humans and new technologies: "New technologies will succeed or fail based on our ability to minimize the incompatibilities between the characteristics of people and the characteristics of the things we create and use". In order to increase safety within the airline industry, the human-machine interaction cycle has to be fully understood and scrutinized. In turn, problem and industry specific training programs should address these particulars with more focus.

McFarland (1973) looks at the relationship between worker and machine as a primary cause of human error. In his work, McFarland develops a model (refer to

Appendix B for a graphic representation of the model) in which he explains the relationship between these two. On the "worker side" of this relationship, he describes a human being's sensory organs as receiving information from the machine's displays, then transmitting information to the central nervous system (all this is influenced by the worker's internal and external environments), then the worker's effectors (e.g. hands, feet) manipulating the machine's controls to perform the machine processes that take raw materials and convert them into some product or part. McFarland (1973) indicates that the machine displays have to be designed in a "user-friendly" or ergonomic manner, in order to facilitate the interaction between the machine displays and controls on one side and the worker sensory organs and effectors on the other. Moreover, McFarland (1973) stresses on the importance of the worker's external environment and individual characteristics, as main factors that can lead to human error, whenever this human-machine interaction occurs.

Indeed, in their work on human error identification, Cooper & Volard (1978) in a paper published in the Canadian journal "Accident Prevention", identify the factors in the environment that can affect human performance at work. They reveal, that in each job there is an optimal condition for performing each kind of task. Stress appears to arise whenever a rift is imposed between the individual and these optimal conditions. As a worker exerts more effort to maintain a given output, whilst in a less than optimal environment, this could lead to accidents. Cooper & Volard (1978) classify the following "environment" factors that affect human error in the workplace: thermal stress (the combination effects of air temperature, humidity, air movement and radiant heat exchange), illumination (including such matters as light intensity, brightness contrast, distribution of light etc.), air pressure (altitude, underwater/underground), and noise.

These cardinal factors have to be examined and acted upon in pilot training, since, they relate closely to the cockpit environment and pilot-aircraft interaction. Nevertheless, in this paper the main focus is on the individual characteristics and skills of a pilot and their effect on error.

The Individual. Three fundamental individual-linked aspects can contribute to the occurrence of human error: the physical characteristics, the psychological characteristics, and the interactive/social characteristics. The various physical and psychological characteristics of workers are examined closely by Cooper & Volard (1978) in order to evaluate their impact on industrial safety. In light of the fact that the nature of the task itself could vary from one job profile to another, the study highlights how the job-specific variables could also have an impact on human error. For instance, good visual acuteness may be imperative to safety of bus driving, but may have little significance and impact for pick and shovel work. The relevancy of the factors examined, is essential when profiling the needs of an industry. The arrays of variables that are classified under physical characteristics include (Cooper, & Volard, 1978): age, experience, fitness, health and physical defects. The variables of psychological nature include: intelligence, mental ability under pressure or after long hours of work, perception and motor ability, and, personality emotional factors.

Most importantly, in this paper, great deal of attention should be given at interactive and social factors behind pilot error, since, the DLR study demonstrates that four out of eight factors that are 'very relevant' to the job of an airline pilot are associated with interactive and social skills. For this purpose, it is essential to closely scrutinize how such factors can affect human error in the case of the airline industry.

Interactive and Social Factors behind Pilot Error. Icon consulting, Human Reliability Associates and IATA Aviation Information and Research (2001) have presented to the European Joint Aviation Authorities (JAA) a list of several human errors, that originate in pilots in the aviation industry, and that are caused by interactive and social skill factors. The following table summarizes these errors along with their influencing factors.

Information acquisition Source	**Error Types**	**Factors influencing Error**
Standard Operating Procedures (SOPs[+])	Failure to monitor information sources	Lack of clarity or roles and responsibilities arising from different interpretations of SOPs
Information sharing Process	**Error Types**	**Factors Influencing Errors**
Information sharing between flight crew	Failure to detect primary error (monitoring failures) Failure to challenge incorrect decisions or actions	Command structure on flight deck Lack of verbalization about problems due to assumptions about shared SOPs)
Aspect of Interpretation	**Errors Types**	**Factors Influencing Errors**
Interpretation of simple information Interpretation of higher level meaning Shared knowledge of other crew member attitudes and knowledge	Misinterpretation Surface meaning of messages understood, but higher level significance not appreciated Incorrect expectations arising from different cultures or experience understanding Boredom leading to lack of vigilance	Language Differences Use of unfamiliar terminology Lack of social communication during or between flights leading to failure to build up shared knowledge of experience and attitudes
Decision Making Process	**Error Types**	**Factors Influencing Errors**
Decision making in high time pressure and high risk situation	Only easily available information used-leading to premature hypothesis	Level of experience Quality of information provided in cockpit
Choice of action in standard (i.e. included procedures) contingency situations)	Pilots used to differing procedures may not coordinate effectively	Degree of difference between procedures normally used by different crew members

Table 1: Pilot Error Caused by Interactive and Social Factors (JAA, 2001).

[+] SOPs are the Standard Operating Procedures of every phase of a flight; pilots must adhere to SOPs in order to ensure flight safety.

The above table demonstrates the importance of Standard Operating Procedures on the verbalization of problems between pilots, and on the command structure and clarity of roles in the cockpit. The table also reveals that assertiveness, resilience, the lack of social communication between cockpit members, and the absence of experience/knowledge exchange between flight crews, are behind crew coordination error. In the above table, it is also apparent that pilot decision-making error is highly related to interactive and social factors, since it can result from the lack of crew communication and the poor design of SOPs (absence of information related to interactive/social factors in Standard Operating Procedures and non-standardization of SOPs).

Although diverse, the above types of errors do not encompass all possibilities. Nonetheless, these provide examples of possible errors that could be encountered within the aviation industry, and in turn what aspects of human error should be dealt by in pilot training. Moreover, the above factors reveal how complex the design of a training program aimed at reducing pilot error actually is, and, reveal the existence of numerous factors that can affect the human element in aviation. This serves to substantiate the issues and areas that have to be taken into consideration when creating such programs within this industry.

Indeed, the increase in technology and automation in today's organizations magnifies the demand on the human being performing a particular task. This results in new and important factors that can cause additional human error in the workplace, and, in turn, necessitates training programs that cater with the new requirements of the job (Goldstein, 1986). The evaluation of the development of these training programs is essential, in order to determine their efficiency in reducing particular types of errors.

This being said, an examination of training targeting the human element in aviation resulted in the realization of a new program that addresses this issue, and, revolutionizes the way aviation professionals are being educated. Crew Resource Management training, is now the leading, and, most widely used program of its kind within this industry. This paper assesses whether the evolution of this training helps decrease particular types of pilot error.

CREW RESOURCE MANAGEMENT

Prior to the assessment of the evolution of Crew Resource Management (CRM), CRM and its purpose will be defined, the different stages of its evolution within the United States will be exposed, and, ultimately means by which to assess this training will be discussed.

Defining Crew Resource Management

In the 1979 NASA workshop on Crew Resource Management, John K. Lauber, a psychologist member of the National Transportation Safety Board, defined CRM as "using all available sources—information, equipment, and people—to achieve safe and efficient flight operations". Referring to Seamster, Boehm-Davis, Holt, & Schultz (1998), CRM is the development of crew performance vis-à-vis the more cognitive and managerial aspects of flying. This further encompasses skill training with respect to technical issues associated with the more psychomotor aspects.

The CRM training is considered as one of the most effective methods aimed at minimizing the influences of human error. CRM is one method of addressing the challenge of optimizing the human / machine interface and accompanying interpersonal activities. These activities encompass team building and maintenance, communication, problem solving, decision making, maintaining situational awareness, and dealing with automated systems (JCAB, 1999). Neil Krey[5] (1996) further defines that the main purpose of CRM is to improve crew and management consciousness of human factors, which could cause or intensify incidents, and, in turn positively influence the safe conduct of air operations. Also, CRM uses human resource management knowledge, skills and attitudes to perform and run aircraft operations, and, to entirely amalgamate these techniques throughout every facade of the airline culture, in order to ultimately prevent incidents and possible accidents. Moreover, Neil Krey (1996) states that CRM enables the use of human resources and skills in order to combine commercially efficient aircraft operations with safety. It also improves the working environment for crews, as well as all employees that deal with flight operations and safety.

All of the above definitions on Crew Resource Management reveal the aviation industry's awareness of the importance of the human element, in the reduction of aircraft mishaps. It is through targeting human error in the cockpit, that airline safety practitioners were able to develop the concept of CRM, and, eventually

[5] Crew Recourse Management and Aviation Human Factors research and consultancy firm.

CRM training. An examination of the philosophy through which CRM aims at avoiding human error is presented next.

CRM and Human Error Avoidance in Aviation

If we are to concede that human error is preventable, CRM can then be defined as a training program that countermeasures error, with three lines of defense (Helmreich, 1996)[6]. The first line of defense is the prevention of error from the source: by applying existing knowledge acquired through training, to minimize occurrence of human error. For instance, upholding situational awareness through alertness, and, the prevention of disruptions, can avert navigational errors.

The second line of defense revolves around the training of people on preventive methods and actions necessary to entrap possible error prior to a time when it can become significant or dangerous. For example, a pilot must take necessary actions and precautions prior to entering a stormy weather, and, not just while encountering stormy weather, regardless whether the storm is significant or not.

The third line of defense focuses on the training of people on minimizing the consequences of those errors that may occur. For instance, if the aircraft enters a dangerous stormy area, it is recommended that the pilot review the specific procedures for these types of situations, and thus avoid making a wrong decision, which could ultimately lead to disaster. In his work on CRM and human error

[6] Dr. Bob Helmreich (The University of Texas at Austin) is one of the most recognized figures in CRM research and one of the developers of the concepts of the upcoming 5th generation CRM.

reduction in aviation, Helmreich (1996), profiles these three lines of defense in a pyramid shaped model known as the 'Error Troika' (Figure 1).

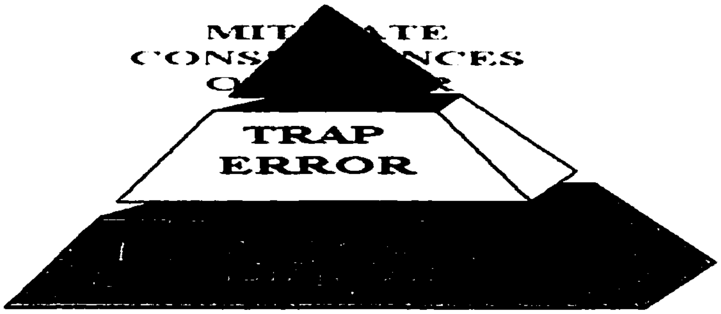

Figure 1: The Error Troika (Helmreich, 1996).

Through these lines of defense, organizations implement a basic rule in training, which ultimately results in the creation of a "safety culture" (this 'error troika' must be thoroughly explained to trainees before CRM training is launched). Through CRM training, companies measure success and strengthen positive accomplishments so as to create and maintain a safety culture. In this respect, organizations do not proceed towards the punishment of failing acts, rather, they encourage the workforce to report all types of human error including inconsequential ones. This provides a much wider array of accident data to draw conclusions from, and thus offers a deeper understanding of how to proceed when developing training programs to cater to these specific incidents (Eiff, Armentrout-Brazee, & Lopp, 2001).

With the CRM clearly defined along with the three lines of defense, the next phase involves the analysis of the evolution of CRM training throughout the years.

The Development of Crew Resource Management

As stated previously in this report, NASA originally created CRM in the United States in 1979 based on the need to extend pilot training to encompass interpersonal communications, leadership, and decision-making skills. Nonetheless, despite the fact that the need for human resource training was felt in the industry at that time, no training programs were yet developed or offered to any airline to cater to these. It was only with the beginning of the 1980s, that these needs were finally addressed through gradual progression throughout the entire industry. This CRM evolution was split into phases, which were coined by the airline industry by the term "Generations" (Helmreich, 1996).

The 1st Generation CRM. Following the 1979 NASA initiative, United Airlines created the first inclusive aviation human resource-training program in 1981. As the first building block of CRM training in airlines, this was referred to as the 'First Generation CRM' (Helmreich, 1996). Facts acquired after the 1978 United Airlines crash, led the organization's management to be at the root of the decision taken to implement these types of seminars. Analysis of the crash, demonstrates the captain's lack of resilience, situational awareness and cooperation skills, which led him to disregard the co-pilots warnings of an abnormal flight situation, and, ultimately resulted in the unfortunate crash of the airplane (NTSB, 1979). Accordingly, managerial efficiency concepts were the main focus of this "First Generation CRM training".

Particularly, pilots where trained on the adjustment of individual styles and behavior. Taking the United Airlines flight as an example, proper training could have avoided the co-pilot's lack of assertiveness, and, the pilot's lack of resilience, which compounded, led to the crash. Courses were offered in seminars, where pilots were made to discuss their errors in the cockpit, with the aim of ameliorating their individual behavior. Courses included tutorials (games and assignments) that illustrate managerial efficiency concepts such as resilience, assertiveness and situational awareness. However, due to the lack of information available for the aviation industry at the time, these tutorials were unrelated to aviation (Helmreich, 1996).

Despite the fact that many major airlines have followed in the steps of United, the first generation CRM was received by a significant rejection of training from pilots. Labeled as "Unreliable", this first generation of CRM training, was dismissed and considered inconsequential (Helmreich, & Foushee, 1993). It is only later that CRM training began to be taken seriously, and examined more closely.

The 2nd Generation CRM. NASA's introduced in 1986 another CRM training workshop for the airline industry (Orlady, & Foushee, 1987). As a result, problem areas were analyzed more closely, and, possible improvements were discussed, among which were the necessity for CRM training components to be relevant and targeted towards the aviation industry (Helmreich, 1996). In the same year, researchers from Delta Airlines started developing what is now known as the 'Second Generation CRM' (Byrnes and Black, 1993). Essentially, this second generation was based on the managerial efficiency concept originated in the first generation CRM, along with some changes in the content and structure of the program; these are highlighted in the following table (Helmreich, 1996):

1st Generation CRM Training	2nd Generation CRM Training
Generic non-industry related discussion sessions	Core Modular Structure: increase in industry-specific context
Areas touched upon: • Assertiveness in the workplace • Resilience in the workplace • Situational Awareness	Courses include: • Team building • Briefing strategies • Situational awareness • Stress management Certain Modules cover: • Decision-making • Breaking the chain of errors

Table 2: Difference between 1st and 2nd Generation CRM Training (Helmreich, 1996).

The 2nd generation training, with its modular structure, creates a more pleasant atmosphere amongst trainees. Hence, in comparison with the 1st generation training, the 2nd generation further inspires the trainees towards CRM training (Helmreich, 1996). In fact, if the environment and structure of the training program appeals to the trainees, this would motivate them and should reflect positively on the awareness and transfer of training (Quinones, & Ehrenstein, 1997). On the other hand, in their shift from the 1st to 2nd generation CRM, the airlines' major objective was to create the image that CRM is highly related to aviation. Regardless of those efforts in the 2nd CRM generation, the relevancy to the aviation industry was yet to be established, which still caused qualms amongst pilots. Nonetheless, the end of the 2nd Generation saw with it the transition of CRM from its infancy stage to becoming an integral part of aviation training. Ultimately, CRM earned its place within the training curriculum of every major US carrier in 1990 (Birnbach, & Longridge, 1993; Helmreich, & Foushee 1993).

The 3rd Generation CRM. All of the information and knowledge obtained through trials with the first two generations of CRM training, was aggregated in order to pave the way for a 3rd generation (1990 to 1993) which was specifically oriented for aviation training (see Table 3) (Helmreich, 1996). This new generation of CRM training incorporated all aviation systems' features in the courses. The training began focusing on human factors, and, was now offered to any airline employee with a role in flight safety including flight attendants, dispatchers, mechanics, etc. (Reason, 1990).

Even though, CRM training had yet to be standardized and made mandatory in the U.S. by the Federal Aviation Administration (FAA), the 3rd generation was characterized by a joint cockpit / cabin CRM training between major U.S[7]. Carriers operating under the Code of Federal Regulations-CFR part 121*(CFR Part 121 applies to air carriers such as major airlines and cargo haulers that fly large transport Aircrafts)* (Helmreich, 1996).

[7] It is important to note here that in the Airline Industry, companies compete on the financial aspects (marketing, operations, routes, strategies etc.), but when it comes to safety issues, there is a joint cooperation among major airlines in the world. This joint effort is always supervised by official and regulatory aviation agencies such as the FAA, the JAA, IATA and ICAO. Hence, when we deal with safety in aviation, it is recommended that research analyzes safety from a macro perspective of the industry and by following the trends of major airlines that work under the same integrity and standards of official aviation associations (Capt. A. Sardouk (2001), IATA Crew Resource Management Certified, CRM Consultant).

As a result, the 3rd generation was the first program that incorporated CRM training into all airline systems and into every major U.S. carrier-training curriculum between 1990 and 1994 (Birnbach & Longridge, 1993). Table 3 below highlights the aspects of the 3rd generation CRM training.

3rd Generation CRM Training Characteristics	
Developed in the 1st and 2nd Generation Training	Management development training
	Focused on individual management style/interpersonal skills
	Goals to fix the wrong stuff captains; make first officers (co-pilot) more assertive
	Team building
	Situational awareness
	Stress management
	Modular (error chain, individual decision making models)
Developed in the 3rd Generation Training	Systems approach
	Focusing on specific skills and behaviors
	Relation with technical performance
	Emphasis on evaluating human factors
	Special training for check airmen/instructors
	Human resource training for flight attendants, dispatchers and maintenance.

Table 3: The 3rd Generation CRM Training Features (Helmreich, 1996).

The 3rd generation offers higher quality training than previous generations, since it focuses on specific skills and behaviors and relates CRM with technical training, hence, enables trainees to have a better application of training in their every day tasks (Helmreich, 1996). Indeed, the transfer of training is more effective if the training program addresses specific job-related KSAs (Tracey, Tannenbaum, & Kavanagh, 1995). Moreover, the 3rd generation CRM program introduces human factors in pilot training, which ameliorates the working environment inside the cockpit (enhances the interaction between crew members and avionic systems in the cockpit). Further, the opening of CRM training to professionals outside the cockpit has a positive effect on aviation safety; those being key players in many airline operations (Helmreich, & Taggart, 1995).

The enhancements created in the 3rd generation triggered the need within the U.S. aviation community for the CRM training to be in the hands of an official agency. Further, it was undeniably apparent by this stage, that Crew Resource Management should be incorporated into all aspects and phases of aviation training and operations (Helmreich, 1996).

The 4th Generation CRM. With the creation of the Advanced Qualification Program (AQP) for the FAA by Birnbach and Longridge (1993), all major U.S. carriers operating under CFR part 121, were required to implement CRM as part of flight crew and technical training (Helmreich, 1996). With this shift, the FAA has developed what is known as the 'Fourth Generation CRM' in 1994. It was the first time ever, that large U.S. carriers had to supply a fully detailed CRM training description for each type of aircraft to the FAA. Consequently, all CRM training was now regulated and standardized across all major U.S. carriers. Crewmembers and instructors had to follow a standardized and certified CRM training in 'full mission' simulation, which was without precedent in previous CRM generations (Helmreich, 1996). Further, incorporating CRM into the Standard Operating Procedures of the aircraft was firmly implemented through all U.S. airlines in 1994. In fact, human behavior features where added to a large number of technical procedures, including procedures that dealt with non-common situations in aviation (Helmreich, & Taggart, 1995).

For many aviation specialists, the 4th generation CRM empowered the industry to reduce human error in the cockpit, and, ultimately facilitated the integration of CRM into technical training (Helmreich, 1996). Nevertheless, research in this field is still maturing, and this area of study needs extensive analysis in order to really assess whether the 4th generation CRM has actually contributed to the reduction of human error within the industry. With reference to the 3rd generation CRM training, the below table (Table 4) highlights the evolution of these into the 4th generation.

Differences between 3rd and 4th Generation CRM Characteristics (Features generated in the 4th Generation)
CRM integrated into technical Standard Operating Procedures
Evaluation of human recourse and human factors in full mission simulation

Table 4: Differences between 3rd and 4th Generation CRM Characteristics (Helmreich, 1996).

Precisely, this thesis will assess the shift between the 3rd and 4th generation CRM. This paper will compare the 3rd and 4th generation CRM training by determining whether the 4th generation training (characterized by the integration of CRM principles into SOPs and the introduction of simulation sessions in CRM training) has a significant impact on the reduction of three types of pilot error: crew coordination, decision-making and adherence to SOPs). In order to fully understand the development between these two phases, it is vital to scrutinize the characteristics presented in the 4th generation training.

CRM incorporated into Standard Operating Procedures. The 4th generation developed new flight procedures in a manner, which emphasizes specific CRM elements by incorporating these elements into old SOPs; including, their design in a way to cater to normal, and, abnormal flight situations (Seamster, Boehm, Hotl, & Schultz, 1998). Further, these "new and improved" SOPs, aided crewmembers in ameliorating overall crew communication, by developing a consistent pattern of crew coordination. As a constant reminder to the importance of CRM within the operational environment, these 4th generation SOPs further served as a constant reminder to pilots with regards to consistent procedure adherence (Seamster, Boehm, Hotl, & Schultz, 1998). SOP checklists incorporated CRM in a manner where crew decision-making was enhanced and prepared for possible difficulties or errors prior to their occurrence (Refer to defense line 1 from the Error Troika) (Helmreich, 1996). In fact, during lower levels of workload, takeoff procedures now require the crew to address situational awareness aspects relevant to a takeoff, which ultimately serve to enhance decision-making during takeoff. For instance, the clearance (low level of workload period) procedure represented in Appendix C requires from the pilots to plan for any abnormal situation that can occur after takeoff. This prepares the crew to quickly undertake correct decisions in case any difficulty is encountered after the plane has taken off the ground. Moreover, referring to the preflight procedure in Appendix C, the SOP identifies the crewmembers' roles and asks them to back each other up with decisions. The procedure also requires a constant communication among the crew, it reminds of the necessity of teamwork and encourages the crew to ask questions and clarify doubts and concerns. Clearly, this reengineered SOP aims at enhancing crew coordination by reducing the captain's assertiveness while specifying its necessary role, and, by encouraging communication and teamwork In addition, this preflight SOP ameliorates the decision-making process in the cockpit, by requiring crew members to make decisions as part of a team and not individually.

In conclusion, these new procedures were rendered less complex, more "user-friendly", and were targeted at increasing "pilot adherence to SOPs" (Seamster, Boehm, Hotl, & Schultz, 1998).

Evaluation of human resources and human factors in full mission simulation. Part of the training incorporates the use of a controlled environment in which crewmembers can experience conditions approximating those of actual flight, through the use of a flight simulator. The simulator, which completely replicates an aircraft's cockpit, has the capabilities of simulating aircraft maneuvers such as rolling, pitching, and yawing motions. A computer system coordinates all of the latter by simulating video situations outside the cockpit as well as instrument readings inside it. The trainee controls the inputs, the position of the simulator, information about the aircraft's characteristics, and information about the terrain over which it is supposed to be flying – whilst the automated computer system, does the rest (Dargahi, & Putze, 2001).

The advantage of flight simulators lies in the fact that it takes normal flight training to a further level, by putting the crew in a "real flight" situation – all within a controlled environment. Further, this also allows CRM flight simulation training to closely scrutinize individual crewmembers, and thus evaluate all behavior and responses within a realistic context. Hence, flight simulator training offers the perfect tool for the training of crewmembers on teamwork whilst flying under specific flight conditions, which in turn ameliorates crew coordination (Seaman, 1999).

The 4th generation utilizes the flight simulator to practically apply and incorporate all the knowledge obtained from the CRM course material, by putting flight crew members under specific conditions within the simulator cockpit (Byrdorf, 1998). For example, one simulation-training situation requires the flight crew to perform a takeoff operation facing obstacles such as: thunderstorms, turbulence on departure and low visibility (see Appendix D).

To fully understand the 4th generation simulation training, each of the 3 phases incorporated within this has to be fully examined. The first phase consists of a self-reporting assessment of each crew, to be completed individually by trainees (CRM assessment form in simulation training, along with specific CRM simulation situations are presented in Appendix D). The second phase is the flight simulation exercise, and, upon completion of the simulation exercise, the third phase begins. In the third phase, each individual crewmember is required to evaluate their behavior in the simulator and in turn update the assessment form completed in phase 1. Throughout all of the exercise phases, the instructor completes a separate assessment form on the examinee. This is then combined with the results of the computer output of the flight simulator (maneuvers analyzed by computer system), in order to evaluate the overall trainee performance, reactions, course understanding and adherence to the

4th generation SOPs (Seaman, 1999). Consequently, this allows each crewmember to compare the original self-assessment with that of the training instructor, as well as the other trainees, thus creating a forum for error evaluation, improvement and constructive dialogue (Byrdorf, 1998). Indeed, the CRM simulation training enables crewmembers to obtain feedback on their performance throughout different flight situations that pose different threats, obstacles and test various aspects necessary for harmonious crew coordination. The feedback then received from subordinates, superiors and instructors further educates pilots on improving communication, coordination and decision-making within diverse flight situations. It should be noted that questions are encouraged throughout the training process (Byrdorf, 1998).

Indeed, this new type of training resulted in a re-engineered education program for airline pilots. The assessment of this "Revolution" by the industry's specialists and professionals is discussed in the following section.

Crew Resource Management Training: The Specialists' perspective

In their research on CRM, Helmreich and Foushee (1993) interviewed a large number of aircrews that have completed the CRM training, and, the research findings indicate that CRM has significantly improved flight deck attitudes. Another survey by Helmreich and Foushee (1993) further demonstrate that CRM training did in fact produce the desired results of a positive change in airline personnel behavior vis-à-vis airline safety. Seamster, Boehm, Hotl, & Schultz (1998), after studying CRM training inside major U.S. carriers, further substantiate these views, by stating that CRM training has positive impact on flight crew coordination and decision-making.

Helmreich and Reason agree that the most efficient, and, effective methods in error avoidance strategy is the implementation of CRM training. This being said, both professors further concur that for training to be assessed and its impact measured, additional research is crucial. Extensive research into all facets of this training has to be performed. In turn, this paper analyzes the difference between the 3rd and 4th generation CRM, in order to determine whether the industry is indeed advancing in the right direction with regards to human resource training.

Regardless of the complexity of the assessment, and, for that matter, that of the airline industry, with over 70% of aircraft accidents caused by human error, this evaluation is critical. Moreover, one of the positive side effects that might be gained from this assessment is the confidence enhancement of the personnel that achieve increased adherence to training instructions. Indeed, positive crew response to training is critical for training efficiency (Petersen, 1996). If perceptions of the trainees do not reflect confidence in the training, its relevancy to their work and its effectiveness, undoubtedly, the full potential of the training will not be exploited. Three elements, that could affect crewmember judgment and perception vis-à-vis the quality of the training program given, are discussed by Neil Krey (1996).

The first element is the direct practical relevancy of the training program. The link between direct practical relevancy of training and the improved performance of pilots should be highlighted, by molding general perceptions (especially amongst pilots), to view training as firstly vital, secondly relevant, and, finally effective. Consequently, any negative perceptions will be reduced, which results in a training that is received with more enthusiasm and appeal. The second element is the incentive for the training. With "safety first" as the central element within the aviation industry, criteria for measurement of pilot credibility and performance, have to also incorporate this philosophy. A pilot training should be viewed as "incomplete" if the CRM safety training has not been completed. The necessity of being "safe" within the industry's "safe" culture has to be highlighted, stressed and implemented. Without which, pilots would not be considered at par with today's aviation safety demands and requirements. The third element is the benefits received from CRM training. The outcomes of the training extend beyond the knowledge learned, and the perfected skills acquired. One of the greatest advantages this training benefits from is the appeal it receives from a "fun" perspective. This is a vital element, which increases training appeal and thus makes it more effective.

Having thoroughly investigated how Crew Resource Management training has evolved throughout its "generations", and, after illustrating some research perspectives about this issue, the focus is now turned on how this research assesses CRM training development. This paper will evaluate the evolution from the 3rd to the 4th generation CRM, using accident/incident data from major U.S. carriers. By combining the results of this research with the results previously obtained from CRM training research, an overall assessment of this program can then be effectuated.

EVALUATING CRM TRAINING THROUGH AIRLINE ACCIDENT DATA

In order to assess the achievement of set training objectives, an evaluation of the source has to be conducted, thus going back to the initial training program. This evaluation can be conducted following three main systematic methods (Hendrick, 1990).

The first method of evaluation is conducted with the use of a combination of quantitative, and, qualitative research methods. Questionnaires and interviews, are given to the trainee by management or researchers of the program, in order to uncover participant perception of the effectiveness of the training (Vojetcky, & Schmitz, 1986). The questionnaires incorporate rating scales on specific elements of the program, as well as, blank spaces for respondent general comments and views. Feedback received from participants helps assessing the program value, worthiness, and its efficient application. These questionnaires are conducted in parallel with interviews aimed at uncovering qualitative elements, which may have had an impact on respondents. Aspects such as perception, image, spontaneous reactions and associations to the program combined with the results obtained from the quantitative questionnaires, aid in drawing a more complete evaluation (Hendrick, 1990).

The second method of evaluation entails a thorough documentation of the training program through scheduled inspection and evaluation of all its pertaining elements (Hendrick, 1990). This evaluation is generally conducted by specialized safety people, or, by supervisors from within the organization, in order to assess whether company operations are being conducted in a manner compliant with the training content and goals (Terrell, 1995).

The third method of evaluation consists of the overall examination of varying types of data including: accident/incident records, lost time medical data, compensation costs or mishap-related injuries (In aviation, this method is defined by the FAA as the 'Accident Causation Method') (Hendrick, 1990). The evaluation is focused on the change in one or more of these variables, within a specific time increment (example: before and after the training) (Terrell, 1995). Further, Heinrich (1940) states that any safety program or related training should be executed through a detailed analysis of accident data and the pertaining causes of these. Moreover, he indicates that more than 80% of accidents are due to human error, which can be lessened with focused safety training directed towards the organization's human element. As one of today's most widely used accident causation management theories, Heinrich's concept is still highly recommended by specialists and professionals within various industries. (Feyer, & Williamson, 1991; Andre, 2000).

It is important to note, that a bona fide evaluation of a training program, can be achieved through the amalgamation of all of the above methods. Consequently, this achieves a broader program measurement due to the analysis obtained from multiple sources (Hendrick, 1990). The cardinal focus of this research lies in determining the CRM training evolution (from 3rd to 4th generation) effectiveness in reducing particular categories of human error in the aviation industry. As a predictor of CRM training evolution effectiveness, different categories of human error rates in aircraft accident/incident data will be utilized in this paper. Towards this end, it is vital to analyze these "particular categories" through their own variation, as a means to understand the 3rd to 4th generation CRM training evolution.

Categories of Human Error to Observe

Taking into account all leading causes of accidents/incidents within major U.S. carriers between 1990 and 1999, this research will classify accidents/incidents that were triggered by human error into four identifiable categories, which are then assessed. These categories are constructed in accordance with the 4th generation CRM training characteristics, in order to determine whether the shift between the 3rd to 4th generations was indeed effective in significantly increasing flight safety (In the following section "Pilot" refers to Captains and/or Co-pilots). The four chosen categories comprise:

Pilot "crew coordination" Error: failure to defy incorrect decisions or actions, failure to build up shared knowledge among crewmembers, lack of problem verbalization, lack of awareness on the actions of the other crewmembers, misinterpretation of information between crewmembers. These types of errors should be reduced through full mission simulator CRM training and through the introduction of CRM into SOPs.

Pilot "decision-making" Error: erroneous response or action under high pressure/high risk situations, erroneous decision-making due to lack of experience in a particular situation, premature decision-making, decision-making based on unverified information. This type of error should also be reduced through full mission simulator CRM training and through the introduction of CRM into SOPs.

Pilot "Standard Operating Procedure adherence" Error: failure to refer to particular SOP, failure to follow SOPs in assigned order, erroneous interpretation of an SOP under normal conditions, erroneous interpretation of an SOP under abnormal conditions, infringe / contradict SOPs under normal conditions, infringe / contradict SOPs under abnormal conditions. Pilots were trained to adhere to new "optimized" procedures implemented in the 4th generation, which incorporate CRM into all SOPs. This flight SOP innovation should allow pilots to better use, understand and implement these new procedures.

Error of professionals outside the cockpit: these are defined as the errors committed by airline professionals outside the cockpit (error of mechanics, flight attendants, aircraft inspectors, or company management). Due to the fact that the content of the CRM training conducted for these personnel remained unchanged from the 3rd to the 4th generation, a significant variation should not be observed through the evolution. In light of this, this type of error is only used for analysis purposes in order to better assess the change in the aforementioned categories (Pilot 'crew coordination' error, Pilot 'decision-making' error, Pilot 'adherence to SOP' error).

Concisely, the following paragraph entails the model of the CRM training evolution as well as the hypotheses to be assessed in this research paper.

Modeling the Hypothesis

Specific time increments marked both the 3rd and 4th CRM generations. The 3rd generation emerged in 1990, followed by the introduction of the 4th generation in 1994; the latter defining the safety training parameters of major U.S. carriers to this day.

In order to assess the effectiveness of the evolution of CRM training in reducing accident/incident rates caused by human error, both the 3rd and 4th generations need to be analyzed by contrasting the accident data within each. So as to uncover existing human error, each set of accident data is to be analyzed with its corresponding generation, and, in turn compared to the other. In assessing the progression in CRM training, research questions must be based on criteria that clearly distinguish between generation training characteristics. Basically, the main differences between the 3rd and 4th generation are the introduction of CRM into Standard Operating Procedures (with technical issues), and the CRM training being conducted in full-mission simulators. Referring to the general theory on training, the development of new work procedures and training employees on them, enable the trainees to have a systematic understanding of the tasks they are to perform in normal and abnormal situations. Moreover, simulation training allows a better transfer of training since the employees are being educated under real-life settings (Friedman, & Yarbrough, 1995). The principles of CRM being introduced into SOPs and pilots taking CRM training in full-mission simulators should have a significant effect in decreasing human error in the cockpit. This transition in CRM training and its effect on particular human error rates are illustrated in the following model.

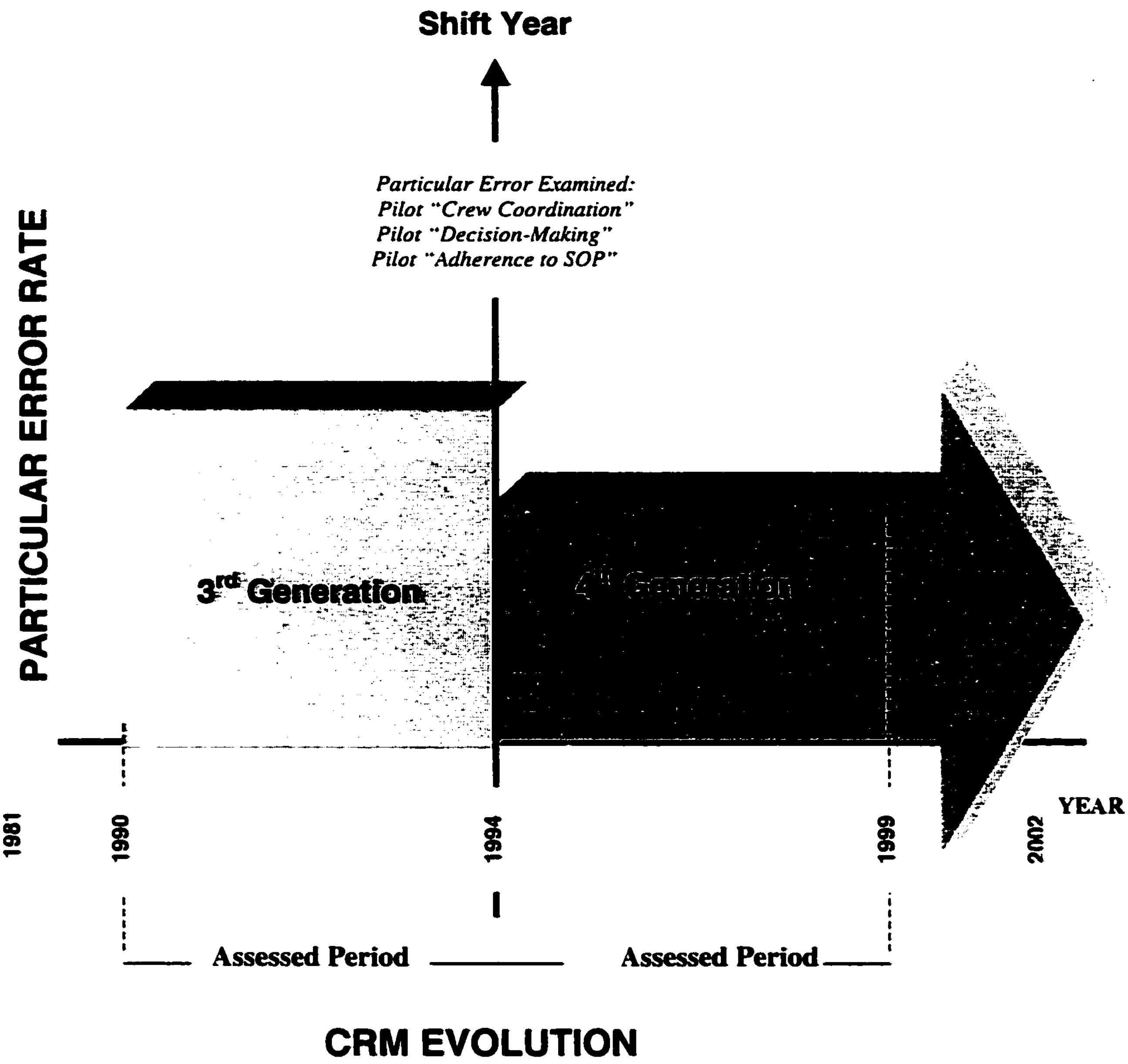

Figure 2: Fault Reduction (FR) Model: From 3rd to 4th CRM Generation Training.

Towards this end, the following hypotheses take shape:

Hypothesis 1: the 4th generation Crew Resource Management Training reduces Pilot 'Crew Coordination' Error.

Following CRM principles being incorporated into SOPs, and, the introduction of flight simulators within the 4th generation, Pilot 'Crew Coordination' error should demonstrate a significant decrease. The positive effects of re-enacting a real-life cockpit situation using the simulator in the training should also enhance pilot communication and overall harmonious interaction; thus resulting in decreased human error for this element.

Hypothesis 2: the 4th generation Crew Resource Management Training reduces Pilot 'Decision-Making' Error.

In light of the fact that within its 4th generation, CRM training was fully incorporated into SOPs, in combination with training being conducted with the use of flight simulators, a positive bearing in Pilot 'Decision-Making' Error should be attained. Reduction of premature, erroneous as well as unverified issues associated with this category of human error, would be significantly decreased.

Hypothesis 3: The 4th generation Crew Resource Management Training reduces Pilot 'Standard Operating Procedure Adherence" Error.

Due to the fact that the SOPs are at the core of the safety of a flight, the differences from 3rd to 4th generation, are cardinal in the evolution of the aviation industry's "safety first" philosophy. As the FR model illustrates, the evolution of the CRM training into its 4th generation should have a positive impact on the reduction of pilot "SOP adherence" error.

On the other hand, the error of professionals outside the cockpit should not exhibit any change (upward or downward) after the introduction of the 4th generation CRM training, since the only differences between the 3rd and 4th generation exists for airline pilot training.

METHODOLOGY

The 'Fault Reduction' Model and its corresponding hypotheses can be best assessed through three different methods: interviews and questionnaires on a sample of 'pilot' CRM trainees, internal safety audits of several airlines, and/or, the thorough examination of aircraft accidents/incidents causation records. This research employs the latter method 'Accident Causation Method' as means to analyze the above stated hypotheses. As mentioned previously in this paper, this methodology is highly recommended in safety work, since it scrutinizes in a highly dependable manner the genuine outcome and results of safety training programs. The methodology will use archival data covering a specific time period; this type of methodology is sometimes observed as being sloppy and with no control and is susceptible to internal validity risks because of the absence of control situations that allow a valid assessment of the changes (Kazdin, 1992). Nonetheless, these sorts of problems that can be encountered in this kind of research can be resolved if the research is cautiously planned (Whitley, 1995). The methodology used in this paper overcomes different troublesome aspects that can affect the research results; the reliability and validity of the evaluation will be described in the discussion section.

In the case of the aviation industry, CRM is the ultimate contemporary safety training that deals with human error avoidance. This methodology attempts to illustrate the relationship between CRM training evolution and the pilot error rate trends (taken from accident/incident reports) over a particular period of time. In order to significantly demonstrate a relationship between CRM training evolution and pilot error rate, the accident/incident sample analyzed must be relatively large since accidents and incidents do not occur often (on a daily basis) in the airline industry. For this purpose, all 'final' accident/incident causation data sheets included in the NTSB 'Aviation Accident Database', from 1990 till 1999, for all U.S. carriers operating under CFR Part 121 (Scheduled and Non Scheduled) were rigorously inspected. This is equivalent to 655-aviation accident/incident encountered over 139,414,080 of flight hours. Note here that the year 2000 and 2001 were not taken into consideration since the NTSB has not yet finalized the causation investigation of a significant number of accidents for those particular years.

In this research, all judgments are based according to a data causation investigation, obtained from the analysis of reports from the accident and incident database of the United States National Transportation Safety Board. Through a close examination of NTSB records that clearly state accident/incident causes, this paper will attempt to uncover and analyze, human error data essential in the validation of the above hypotheses. Towards this end, an illustration of the role and integrity of the NTSB is presented.

The Reliability of the NTSB in Accident and Incident Investigation

The NTSB is an independent federal agency sanctioned by Congress, with the mandate of investigating every civil aviation accident in the United States. Upholding the government's database for these accidents, as well as the execution of specialized studies and research on air transportation and safety throughout the U.S., are amongst the core responsibilities of the NTSB. Further, according to the "International Treaties for Aviation Accidents" which involves U.S. registered aircraft and chief constituents of U.S. aircraft manufacturers, the NTSB provides investigators to serve as "U.S.-accredited representatives". Moreover, the NTSB operates as the "court of appeals" for flight crews and aircraft mechanics, during any FAA-led certificate acts or civil penalties (NTSB, 2002). In addition, over 110,000 aviation accidents, including thousands of surface transportation accidents and incidents, have been investigated by the NTSB. Indeed, it has developed into one of the world's leading accident investigation agencies with more than 11,600 recommendations in every transportation medium in the United States. Its status and reputation for objectivity and diligence, has allowed the NTSB to attain the status it enjoys as the leading authority in transportation safety enhancements in the US.

In fact, decision-makers within the industry have implemented more than 80 percent of the NTSB recommendations. The NTSB personnel, who study the causes of air mishaps for U.S. carriers, are called: Air Safety Investigators or Aviation Accident Investigators (AAIs). Those individuals must hold an FAA commercial pilot certificate (with airplane single and multiengine land and instrument ratings), in addition to having acquired a certain amount of flying hours and relevant job experience (Norris, 2001).

Decisively, the NTSB is the only agency within the United States, which is empowered to determine the probable cause of national aircraft accidents, and, incidents. Further, the agency possesses the right to acquire court orders for special searches and confiscations, with respect to any individual, or, group who may have pertinent facts affecting an investigation. Indeed, the NTSB earned exclusivity to seize into custody the wreckage, the cargo and the evidence of any U.S. aircraft involved in an accident (Norris, 2001).

The procedure through which the inspection of the NTSB sample in this paper was conducted is described in the following paragraph.

Coding of Causes of Accidents

The NTSB states the cause of each aircraft mishap in an accident/incident causation sheet. This paper examines four different categories of human error in the NTSB sample: Pilot 'crew coordination' Error, Pilot 'decision-making' Error, Pilot 'adherence to SOP' Error and Error of Professionals outside the cockpit (a sample of NTSB accident/incident causation sheets for each category is given in Appendix E). These error categories were identified and coded from the NTSB sample, and, this classification and coding of the categories was conducted by four different coders: An Msc. in Administration Student, Concordia University; a Ph.D. in Engineering Student, Concordia University; a Placement Director for a leading human resource firm in North America, and the author of this paper. Every error category was carefully defined to all coders and they were all trained on the coding methodology process (coders were provided a coding manual constructed for the purpose of this research, see Appendix F). A sample consisting of 10 NTSB accident causation sheets was provided to the coders, and each was required to follow the coding manual, in order to identify and categorize the necessary errors. Following the training, all coders were capable of coding the errors in a standard and consistent manner (There was a total agreement among coders over the 10 accidents sample).

Referring to the coding manual, each coder goes through each and every NTSB accident/incident causation sheet, if an error category is identified in the sample, it is marked by '1' and the coder puts '0' under all other categories. In case the accident/incident cause given by the NTSB does not match any of the categories, 'N/R' (not related) is marked under all categories; N/R is marked for accident causes that are directly related to a technical deficiency (not caused by a human error), a pilot technical error, a pilot human error that is not related to the categories utilized in the paper, an unexpected weather condition, a fire or hazard with unknown reasons, a problem related to the aircraft manufacturer, incident caused by a passenger, collision with a bird or a pilot/co-pilot health problem during the flight. For instance, in Appendix E, when the NTSB states the cause of the accident/incident to be "The pilot's failure to use proper procedures; improper use of the throttles", '1' is marked under Pilot 'Adherence to SOP' Error and '0' below all other categories. On the other hand, if the NTSB indicates the cause of the accident/ incident to be "A laser light source of undetermined origin, directed by unknown person(s)", 'N/R' is marked under all categories.

Subsequent to the coding, the results of the four coders were scrutinized. In only 14 cases were disagreement encountered in the 655-accident/incident sample. Precisely, in 11 cases three coders categorized the accident/incident as 'N/R' and the fourth coder classed the error as error of 'professionals outside the cockpit'. In these 11 cases, the final decision was based on the judgment of the majority (3/1), and these categories were finally allocated to 'N/R'. Further, in 3 other cases, coders disagreed on whether the error should be assigned to 'pilot crew coordination error' or 'pilot decision-making error'. In 2 of those cases the final judgment was based on the majority (3/1) decision, in favor of 'pilot decision-making error', and, in 1 case the decision was split (2/2) among coders, and the final decision was based on the judgment of the author (in favor of crew coordination error).

Calculations

In order to determine the error rate, each category in every assessed year is looked upon, and the number of error for each category for every year is then divided by the amount of aircraft hours flown during that particular year by all US airlines in the chosen sample. The hours flown are taken from the 'NTSB Accident Rates Report (1982-2000)', and are presented in Appendix G. This being done, the error rate trend between 1990 and 1999 for each category is represented in charts in order to demonstrate the change in those rates and compare them with the evolution of Crew Resource Management. The mean for each type of error rate is calculated between 1990 and 1993 (3rd Generation CRM Training) and between 1994 and 1999 (4th Generation CRM Training).

A t-test of the significance of the difference between the means of each studied period (MEAN1 for the period from 1990 and 1993, and, MEAN2 for the period between 1994 and 1999) for each category was conducted (Using a level of significance $\alpha = 0.01$). Note that, in the t-test conducted on the means of each error category for every assessed period, the CRM generations are related, thus the assumption for independence of data was not met in these t-tests.

On the other hand, all fatal accidents during the examined period are further scrutinized in order to assess whether any of the chosen categories was significantly involved in air disasters (all fatal accidents are indicated by the NTSB).

Error categories' trends studied in this research, as well as, the involvement of each error in fatal accidents are presented hereunder. These results will help analyzing the evolution of CRM training, particularly amid the 3rd and 4th generation CRM.

Error Categories' Involvement in Fatal Accidents

Firstly, the percentage of each error category involvement in fatal accidents for US carriers included in the sample (all US airlines operating under CFR part 121 from 1990 till 1999) is presented in the chart below. This is to show the significance of these categories in fatal aircraft accidents, and hence their importance in aviation safety training.

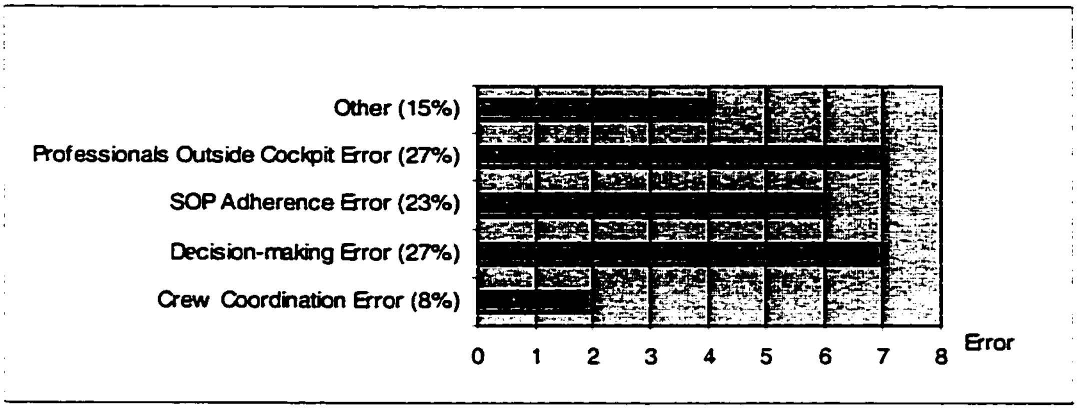

Figure 3: Error Categories Involvement in Fatal Accidents;
US carriers under CFR Part 121 (1990 – 1999).

The category 'Other' in the above chart represents the accidents/incidents causes that were coded in the methodology by 'N/R' (those have been defined previously in this section); these errors were not analyzed or assessed since they are outside the scope of this research. With the error of 'professionals outside the cockpit' being involved in 27% of fatal accidents within the studied period, figure 3 demonstrates that the errors hypothesized in this research were directly behind 58% of CFR Part 121 fatal accidents between 1990 and 1999.

Hypothesis 1: Pilot 'Crew Coordination' Error Evolution

Error rate results for flight crew coordination are presented for every year between 1990 and 1999 in the following table.

Year		Error / Flight Hour (E-07)[8]
3rd Generation	1990	4.94
	1991	3.40
	1992	3.24
	1993	3.15
4th Generation	1994	2.29
	1995	2.22
	1996	1.45
	1997	1.26
	1998	1.19
	1999	1.15

Table 5: Pilot 'Crew Coordination' Error Rate; for US Carriers under CFR Part 121 (1990-1999).

The mean for the period between 1990 and 1993 inclusive was calculated and is equal to 3.68E-07 Error/Flight Hour. On the other hand, the mean for the period between 1994 and 1999 inclusive was calculated and is equal to 1.59E-07 Error/Flight Hour. The result of the t-test for the difference in the means for crew coordination error rate, demonstrates that the means for the two assessed periods are not equal ($t(8) = 4.888$; $p<0.001$). The graph (Figure 4) illustrates the evolution of this type of error through the years and hence offers a tool to assess the effect of the shift from 3rd to 4th generation CRM training.

[8] All error rates are to the power ten to the minus seven.

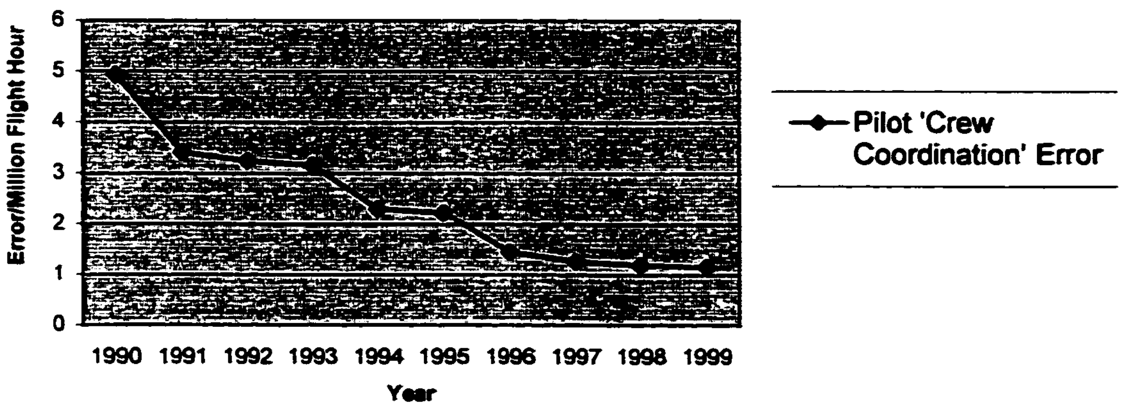

Figure 4: Pilot 'Crew Coordination' Error Evolution;
for US Carriers under CFR Part 121 (1990-1999).

Hypothesis 2: Pilot 'Decision-Making' Error Evolution

Error rate results for pilot decision-making are demonstrated for every year between 1990 and 1999 in table 6.

Year		Error / Flight Hour (E-07)
3rd Generation	1990	6.58
	1991	8.49
	1992	5.66
	1993	8.66
4th Generation	1994	3.81
	1995	2.96
	1996	2.18
	1997	3.16
	1998	1.19
	1999	2.30

Table 6: Pilot 'Decision-Making' Error Rate; for US Carriers under CFR Part 121 (1990-1999).

The mean for the period between 1990 and 1993 inclusive was calculated and is equal to 7.35 E-07 Error/Flight Hour. Also, the mean for the period between 1994 and 1999 inclusive was computed and is equal to 2.6E-07 Error/Flight Hour. The result of the t-test for the difference in the means for decision-making error rate reveals that the means for the two assessed periods are not equal ($t(8)=6.384$; $p<0.001$). The graph (Figure 5) below illustrates the evolution of this type of error through the years and eventually offers a tool to analyze the effect of the shift from 3rd to 4th generation CRM training.

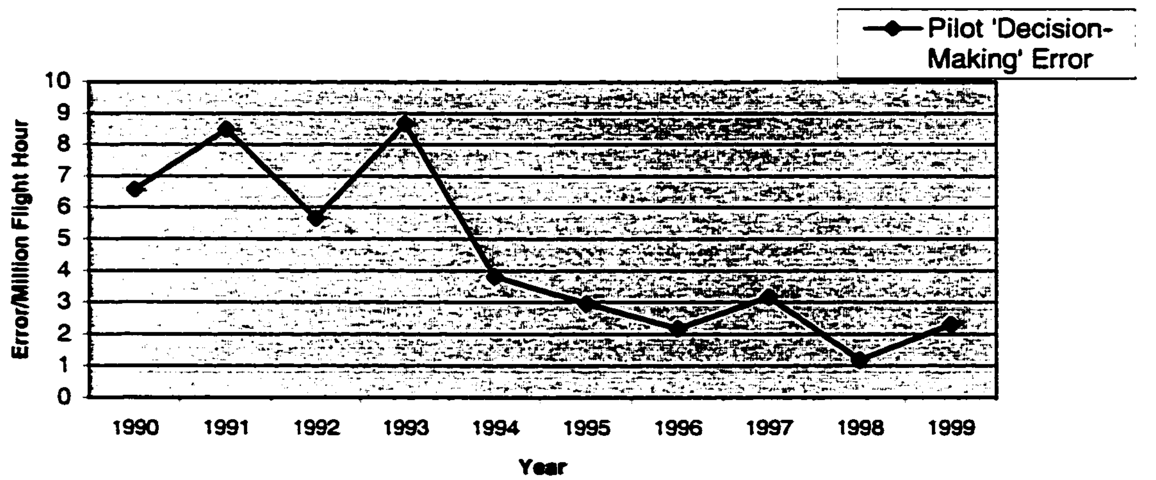

Figure 5: Pilot 'Decision-Making' Error Evolution; for US Carriers under CFR Part 121 (1990-1999).

Hypothesis 3: Pilot 'SOP Adherence' Error Evolution

Error rate outcomes for pilot SOP Adherence are presented for every year between 1990 and 1999 in the following table.

Year		Error / Flight Hour (E-07)
3rd Generation	**1990**	6.58
	1991	5.09
	1992	4.85
	1993	6.29
4th Generation	**1994**	3.05
	1995	2.22
	1996	2.91
	1997	3.16
	1998	1.78
	1999	1.73

Table 7: Pilot 'SOP Adherence' Error Rate; for US Carriers under CFR Part 121 (1990-1999).

The mean for the period between 1990 and 1993 inclusive was calculated and is equal to 5.71E-07 Error/Flight Hour, and, the mean for the period between 1994 and 1999 inclusive was calculated and is equal to 2.47E-07 Error/Flight Hour. The result of the t-test for the difference in the means for adherence to SOP error rate demonstrates that the means for the two assessed periods are not equal ($t\ (8)= 6.839$; $p<0.001$). Figure 6 exhibits the evolution of this type of error through the years and hence helps in assessing the effect of the shift from 3rd to 4th generation CRM training.

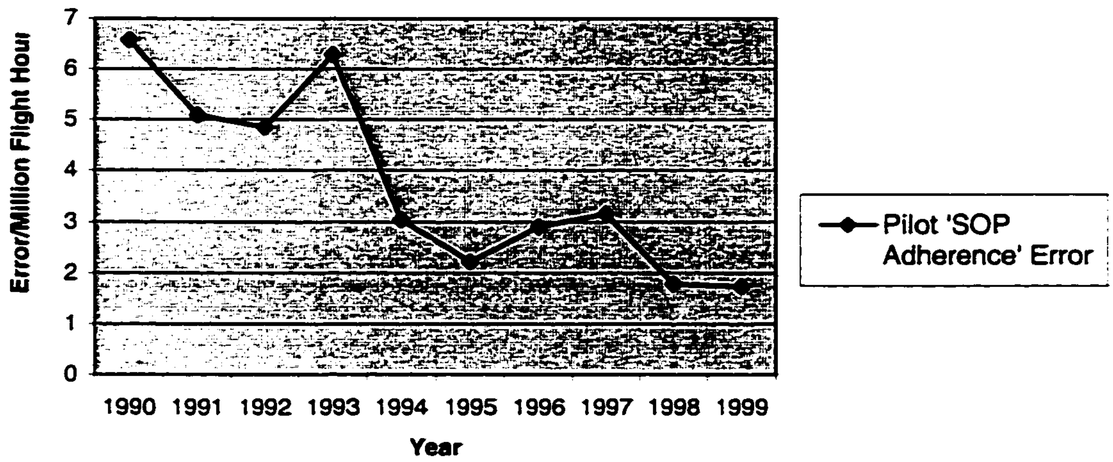

Figure 6: Pilot 'SOP Adherence' Error Evolution;
for US Carriers under CFR Part 121 (1990-1999).

Error of Professionals outside the Cockpit Evolution

Error rate results for professionals outside the cockpit are presented for every year between 1990 and 1999 in table 8.

Year		Error / Flight Hour (E-07)
3rd Generation	**1990**	8.23
	1991	10.2
	1992	8.9
	1993	9.44
4th Generation	**1994**	9.14
	1995	10.4
	1996	8.73
	1997	11.4
	1998	9.51
	1999	9.78

Table 8: Error Rate of Professional outside the Cockpit;
for US Carriers under CFR Part 121 (1990-1999).

The mean for the period between 1990 and 1993 inclusive was calculated and is equal to 9.19E-07 Error/Flight Hour. In addition, the mean for the period between 1994 and 1999 inclusive was calculated and is equal to 9.81E-07 Error/Flight Hour. The result of the t-test for the difference in the means for crew coordination reveals that the means for the two assessed periods are not significantly different ($t(8) = -1.051$; $P=0.15$). The graph hereunder exemplifies the evolution of this type of error through the years and hence helps analyzing the effect of the shift from 3rd to 4th generation CRM training.

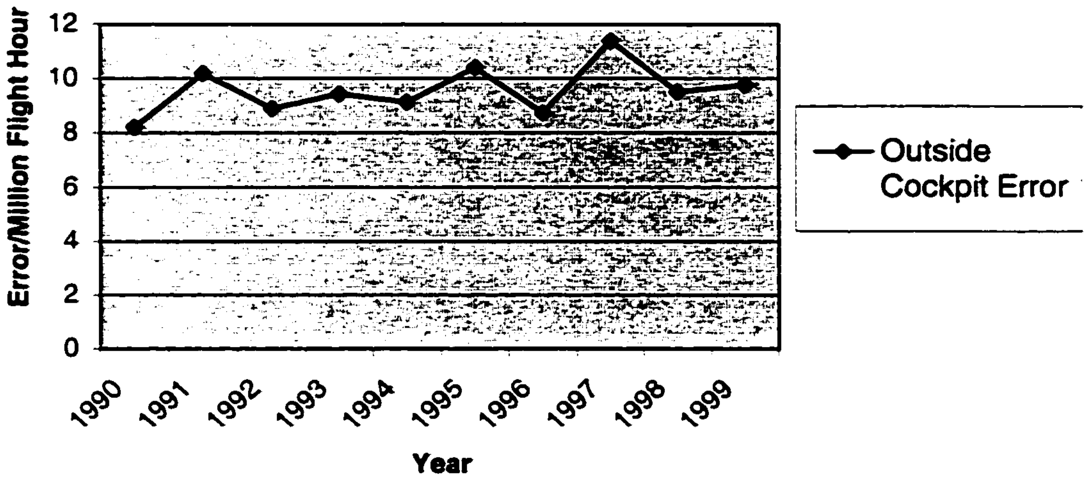

Figure 7: Error Evolution for Professionals outside the Cockpit; for US Carriers under CFR Part 121 (1990-1999).

The above results, along with their implications on research and practice in the airline industry, are discussed hereunder. Further, the validity and reliability of the methodology employed in this study together with final conclusions are demonstrated in the next section.

DISCUSSION

The primary purpose behind pilot training is to lessen human error in the cockpit, and, thus reduce aircraft accidents and incidents. Contemporary pilot job analysis reveals that, with regards to the job of an airline pilot, interactive and social skills are rated as 'highly relevant' or 'relevant'. In light of this, a training program that deals with the reduction of errors related to the aforementioned competencies is of cardinal importance to airline safety. Being the premier human error reduction program used in the aviation industry, Crew Resource Management training plays a fundamental role in decreasing errors related to interactive and social skill factors. The CRM program is the exclusive FAA-approved training module that is used in the United States for the reduction of pilot human error, particularly vis-à-vis interactive and social skill aspects. The aviation industry's awareness of the existing need to reduce human error has been addressed by the creation of CRM training. Nonetheless, this program is still in development, and, in parallel, it is essential to determine the effectiveness of this evolution through various methods.

A training program that takes into consideration central factors in the job analysis, educates employees on procedures that incorporate important aspects of the job, and undergoes work simulation sessions, can have a significant effect in reducing particular types of errors in the workplace. The Fault Reduction model developed in this research, demonstrates that the evolution of CRM training depicts a significant progression towards the reduction of pilot crew coordination, decision-making and adherence to standard operating procedures errors. These are of cardinal importance to the job of today's airline pilots. The FR model through its corresponding hypothesis is tested in this paper by undertaking an accident/incident investigation. The data utilized covers a significant number of aircraft mishaps, in which the shift from the 3^{rd} to 4^{th} generation CRM training is observed. Yin (1984) indicates that the major limitation of archival data usage within research stems from the use of unofficial and skewed data sets. In addition, taking into consideration that aircraft mishaps do not occur on a daily basis, the process of investigating accident or incident data within this industry requires a relatively large sample size. This research employs a sample of 655-NTSB accident investigation sheets incorporating over 130 million flight hours spanning a time period of 10 years. Thus, the data source is highly reliable and the sample size is large enough to validate the conclusions obtained.

Yin (1984) further states that the data utilized could be susceptible to intrinsic factors such as the personal impressions and attitudes of the researcher. This limitation is overcome within this paper by the fact that three different coders plus the author conducted the coding process of error categories in the methodology (with only 14 cases of disagreement emerging between coders across the sample).

Alternately, Whitley (1995) states that in program evaluation, if only one outcome is evaluated and findings indicate that an apparent effect has occurred, that effect could be the result of a combination of chance factors, or, a confound. Whereas, if more than one output is evaluated, and the apparent effect exists across these, then it becomes decreasingly likely that chance or confound were at play. In this research, four variables are analyzed to assess the effectiveness of the evolution of CRM training - from the 3^{rd} to 4^{th} generation- in reducing pilot "human error".

The examination of each particular error rate, in the periods preceding and following the shift, in combination with the comparison of the mean of those error rates amid these two periods, reveals the following findings with regards to each hypothesis.

Hypothesis 1-The results related to hypothesis 1 demonstrate that when the 4th generation CRM training was initiated in the industry—with CRM principles introduced in the SOPs, and, pilots being trained on harmonious interactions and communication in simulators—pilot 'crew coordination' error drops. Taking into consideration that CRM training is the only recognized program to be directed at decreasing "crew coordination error" in the industry, it is noteworthy to observe that a positive impact has occurred on the reduction of this type of error within the investigated time increment. However, in figure 4, the shift year (1994) does not exhibit a substantial plunge in this particular type of error. In fact, the error trend is uniformly dropping over the examined time increment, which undermines the effect of the 4th generation training on 'crew coordination' error. No apparent reason was found to explain why the error is decreasing on an almost constant trend, and, no sharp drop is witnessed in 1994. One plausible rationale could be, that the introduction of the 3rd generation CRM had an important impact on reducing 'crew coordination' error to an extent that it was difficult to directly decrease the error much further following the implementation of the 4th generation training. In fact, compared to the other types of pilot error assessed in this research, the findings demonstrate that within the 3rd generation, 'crew coordination' error has the lowest error rate. Alternately, one could argue that personnel coordination training in the workplace requires a longer transitional transfer period than other types of skills– hence stretching the period over which the error is decreasing. Indeed, if the employees are performing their tasks with personnel different than the ones they have received the training with they might need an additional time on the job to better apply the coordination skills they have acquired through training. This could provide an interesting portal into future research within this field.

Nonetheless, although the slope observed between 1993 and 1994 does not portray a drop of noticeable magnitude, the hypothesis that the 4th generation CRM training reduces pilot 'crew coordination' error is accepted, given the fact that the t-test conducted on the mean of the error rates between the 3rd and 4th generations, proposes a significant difference. Further, the findings obtained highlight a considerable decrease in the error rate mean following the shift period: a much lower mean apparent in the 4th generation These findings support the hypothesis that the 4th generation CRM training decreases pilot 'Crew Coordination' error.

Hypothesis 2-The results associated with hypotheses 2, exemplify that the introduction of the 4th generation CRM training—with its philosophy being incorporated into SOPs, and, the introduction of CRM into the real-life settings of flight simulators—has a significant impact on pilot decision-making in the cockpit. The shift year in figure 5 exhibits a significant drop in decision-making error. In addition, the t-test conducted between the assessed periods of the 3rd and 4th generations, demonstrates that the error rate means between these are significantly different. Indeed, the error rate mean for the 4th generation period is much lower than that calculated for its precedent 3rd generation period. These findings support the hypothesis that the 4th generation Crew Resource Management training reduces pilot 'Decision-Making' error.

Hypothesis 3- The findings linked to hypothesis 3 demonstrate that the 4th generation CRM training—with its philosophy reengineering the standard operating procedures of flight through CRM principles and pilot training on these new procedures in flight simulators— had a significant impact on pilot 'adherence to SOP' error. Figure 6 exhibits a significant drop in pilot 'adherence to SOP' error due to the introduction of the 4th generation CRM training in 1994. Indeed, the error rate mean for the 4th generation period is much lower than that calculated for its precedent 3rd generation period, and, the t-test reveals that the means assessed are significantly different. These findings support the hypothesis that the 4th generation Crew Resource Management training reduces pilot 'Adherence to SOP' error.

The t-test conducted on the error of 'professionals outside the cockpit' shows that the two assessed means for this particular error rate are essentially the same. Indeed, a significant change in the mean error rate from the 3rd to 4th generation training is not observed. As seen in figure 7, unlike the error rates for pilots, the error pattern of 'professionals outside the cockpit' demonstrates a constant trend spanning the examined periods; with no significant change (downwards or upwards) witnessed after the 1994 shift year. The findings related to that particular error are imperative for the support of this research hypothesis. Indeed, control cases can contribute greatly to the evaluation and assessment of progress achieved throughout a phenomenon. By providing a variable to "measure against" or "benchmark", a control case serves as the validation of the factor that has resulted in an apparent effect

(Whitley, 1995). In this paper, the error of 'professionals outside the cockpit' is used as a control variable. In fact, within the shift from the 3rd to 4th generation CRM training, although the manner in which pilots were trained was altered, there was no development in the education of professionals outside the cockpit. A significant change in the error of 'professionals outside the cockpit' rate between the two assessed periods would indicate that a factor other than CRM training is having an impact on human error in the aviation industry. Taking this into consideration, the shift from 3rd to 4th generation CRM training should only demonstrate an apparent change in pilot-related "human error"; as is illustrated in the findings of this paper.

Having addressed and analyzed the results of this research in combination with the FR model and its corresponding hypothesis, the implications of the findings on academic aviation research and practice within the airline industry ought to be presented.

Implications for Research

The 3rd generation CRM training is assessed by Helmreich & Wilhelm (1991), and, Helmreich & Foushee (1993), and the results demonstrate a positive impact on trainee's perception of the program. Helmreich (1996) analyzes CRM evolution across its generations and, in particular, the 4th generation CRM. His study is considered one of the most reliable research sources in the field, revealing that 4th generation training produces positive views with regards to flight crew training techniques and qualifications. Further, Helmreich (1996) research deals with the issue of exporting CRM training beyond the U.S., and, the problems that can arise as a result of this exportation (particularly from a cultural perspective). In addition, Neil

Krey (1996) demonstrates that CRM has a positive effect on pilot awareness vis-à-vis beneficial training impacts such as: increased relevancy to airline pilot job, increased credibility and value for pilots, and finally, enhancement of airline pilots' self-development.

Although Helmreich examines the evolution of CRM training, this paper proposes an assessment of CRM from a different perspective, that of a close inspection of particular error trends. Previous research in the field evaluates CRM by interviewing pilots in order to gauge and profile perception on training. This research paves the way for further assessment of particular error trends for airline pilots, which in turn will determine the program effectiveness in reducing these. The FR model, supported in this study, demonstrates that the changes being introduced in the 4th generation CRM training, help decrease pilot: crew coordination error, decision-making error and adherence to SOP error. The error trends analyzed in this paper are of cardinal impact for the job of an airline pilot. Indeed, if a new job analysis reveals the need to include new factors in pilot training and particularly CRM training, research should assess whether the new training program offered to pilots or professionals in the industry is actually helping in the reduction of errors related to those newly introduced factors.

By providing results that portray the effectiveness of the 4th generation CRM in reducing these errors, this research offers an invaluable tool that can be built upon in further assessment of the program. A research that combines both the results obtained here (CRM training and CRM evolution with regards to particular error rates), and those of trainee perception of the 4th generation CRM, provides a highly reliable analysis of CRM evolution. One that assesses the progression from two different perspectives: the decrease/increase of particular error trends, and, the perception of trainees on training techniques' quality and pilot qualifications.

Moreover, 'personnel coordination' is an important core competency for an organization, and provides a competitive advantage for a firm in the market (Teece, & Picano, 1994). The results related to pilot 'crew coordination' error in this paper suggest that the training for 'personnel coordination' might take a longer period of time to transfer into practice. Hence, organizations that aim at enhancing the coordination skills of their workforce through training, must realize that positive results may not been achieved before a relatively lengthy period of time after training. This theory on 'personnel coordination' training should be further investigated in future research.

On the other hand, this research examines CRM training as a whole, hence, an in depth analysis of separate components of CRM training is important for future research in this area. Further, the effect of factors issues such as the culture of the airlines, the size of the air carriers, and the industry training investment must be looked upon in prospective assessments of CRM training.

This being said, an examination of the implication of this research on practice in the industry is to be demonstrated.

Implications for Practice

One of the factors that enhance trainees' awareness and perception of a training program is the success of the training in reaching set objectives. The research findings of this study can be directly applied towards enhancing student perception of CRM training. The error rates assessed, concern all pilots in the industry, and, by demonstrating the effectiveness of the 4th generation in reducing these types of errors, this research enables airline companies to increase trainee confidence in the CRM curriculum. In turn, this increased confidence will lead pilots to be even more receptive to the actual training, resulting in improved performance in the cockpit.

The application of 4th generation CRM principles within flight simulation sessions has resulted in a training technique that is both motivating and enjoyable for its students. In addition to these positive perceptive elements, the results of this paper clearly demonstrate that, the introduction of simulation training into CRM courses also proves to be an effective method in reducing key interactive and social-related types of errors. It is this effectiveness in enhanced safety, that justifies to the air carriers the time consumed and expenses incurred with Simulation session training.

In parallel, airline companies are heavily investing in pilot job analysis research, and, particularly pilot training on CRM programs. These carriers need a return on their investment, and, need to obtain tangible evidence that the training evolution is taking the right direction. Indeed, a new generation of the CRM program with concentration on cultural factors and safety culture in aviation training is currently in development (Helmreich, 1996). In light of this, the industry needs to be assured of the effectiveness of the CRM training evolution (reduction of particular error rates), in order to fully support further research towards it. By demonstrating the effectiveness of the CRM evolution, the FR model encourages further investment in

CRM research, resulting in new findings, continuous development, and ultimately improved aviation safety.

The Future of CRM Training

Crew Resource Management training revolutionizes the way airline pilots are being educated. CRM deals with critical types of pilot error and has proved to be successful in reducing those errors, which are at the root of a large number of aircraft mishaps. Indeed, Helmreich's findings in combination with other research performed in this field, including this paper; corroborate the significance and impact of CRM in aviation accident prevention.

Finally, the bearing of CRM on the aviation industry in the United States has resulted in enhanced pilot performance and altered perception on aviation training, by increasing safety consciousness and awareness amongst all the major carriers. The success seen in the U.S. has prompted an increased international awareness of CRM safety benefits and in turn, resulted in a significant number of foreign airlines adapting CRM training within their training curriculums. Nonetheless, fixed social and interactive elements cannot be addressed in the same manner across different cultures. In light of this, further development aimed at tackling these factors are to be implemented.

Although the 4th generation has prompted the introduction of CRM into flight simulators, as well as the re-formulation of flight procedures, work directed at implementing the principles of the error troika model into all aspects of training, has yet to be fulfilled. Towards this end, Helmreich and Merritt are introducing new concepts and principles in CRM training, paving the way for an adaptable 5^{th} generation CRM to cater to the needs of both the U.S. and International aviation community. 5^{th} generation CRM training remains greatly unchanged from the 4^{th} (with training principles and techniques being primordial), however, adapts a more direct focal point on the three lines of defense of the error troika. This should also create a proactive organizational culture, one that encourages airline employees to report any encountered incident, hence, offering a wider range of data to use in accident prevention work. With this focus, emerges a need to tackle the cultural barriers (and differences amongst pilots) faced by the exportation of CRM, and thus, the assimilation and further acceptance of CRM principles amongst international carriers. For instance, to tackle to problem of 'crew coordination' error and pilot 'decision-making' error outside the U.S., the CRM training should address these issues taking into consideration that international pilots do not think, interact and socialize in the same manner U.S. pilots do.

Once the 5^{th} generation CRM is to be fully integrated within major national and international airlines, an evaluation and comparison with the 4^{th} generation should be conducted. In turn, this should demonstrate that developed 5^{th} generation CRM principles have in actual fact contributed in accident reduction – thus providing a positive return on training investment vis-à-vis time consumed and costs incurred.

Such as those analyzed in this study, for future research directions, particular error rate development between the 4^{th} and 5^{th} generational CRM training curriculums should be assessed. The unfortunate crash of Air China's flight CA 129 on April 17^{th} 2002 (the primary cause associating the accident with a possible pilot decision-making blunder under severe weather during the final phase of the flight) reveals that a 5th generation CRM training adaptable to international cultures, and with increased focus on the three lines of defense of the error troika is required. This being said, the 5th generation CRM training development and assessment is becoming increasingly vital towards ensuring worldwide aviation safety.

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APPENDICES

APPENDIX A: AIRLINE PILOT JOB ANALYSIS (Goeters, Maschkle, & Klamm, 1998).

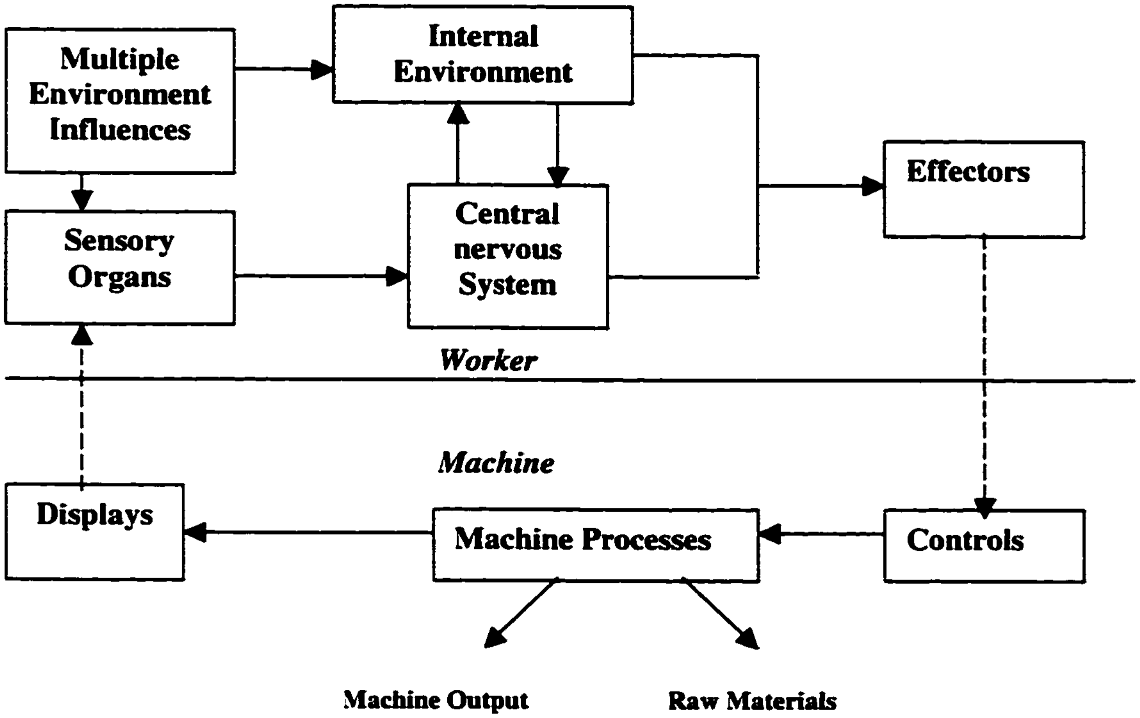
Job Analysis of an Airline Pilot				
	To what extent is the factor relevant for the work of airline pilots?			
	Average Rating			
Area	**Below Normal**	**Normal**	**Relevant**	**Very Relevant**
Cognitive Abilities	Written Expression	Oral Comprehension Inductive Reasoning Originality Fluency of Ideas Category Flexibility Mathematical Reasoning	Problem Sensitivity Speed of Closure Selective Attention Flexibility of Closure Perceptual Speed Number Facility Written Comprehension Information Ordering Oral Expression Memorization Visualization Deductive Reasoning	Time Sharing Spatial Orientation
Psychomotor Abilities	Speed of Limb Movement Wrist-Finger Speed	Mental Dexterity Arm-Hand Steadiness Finger Dexterity	Control Precision Response Orientation Multilimb Coordination Reaction Time	Rate Control

Job Analysis of an Airline Pilot (continued)				
Area	**To what extent is the factor relevant for the work of airline pilots?**			
	Average Rating			
	Below Normal	**Normal**	**Relevant**	**Very Relevant**
Physical Abilities	Static Strength Extent Flexibility Dynamic Strength Trunk Strength Dynamic Flexibility Explosive Strength	Stamina Gross Body Equilibrium Gross Body Coordination		
Sensory Abilities		Near Vision Speech Clarity Visual Color Discrimination Sound Localization	Auditory Attention Speech Recognition Night Vision Far Vision Glare Sensitivity Depth Perception Peripheral vision	
Knowledge & Skills	Drafting	Mechanical Knowledge Electrical knowledge Knowledge of tools and Uses	Reading Plans	Map Reading

Job Analysis of an Airline Pilot (continued)

Area	To what extent is the factor relevant for the work of airline pilots? Average Rating			
	Below Normal	**Normal**	**Relevant**	**Very Relevant**
Interactive/Social Skills	Sales Interests	Oral Defense Persistence Persuasion	Situation Awareness Leadership Self Awareness Resistance to Premature Judgment Behavior Flexibility Resilience Assertiveness Motivation	Stress Resistance Cooperation Communication Decision Making

<u>APPENDIX B:</u> THE INTERACTION COMPONENT OF A TYPICAL WORKER-MACHINE SYSTEM (McFarland, 1973).



APPENDIX C: SAMPLES TAKEN FROM 4TH GENERATION CRM STANDARD OPERATING PROCEDURES FOR PREFLIGHT, CLEARANCE AND APPROACH (Seamster, Boehm-Davis, Holt & Schultz, 1998).

Preflight

Tone - try to follow SOP, new items for today
Crewmembers Roles-back each other up with decisions
Crew Communication-keep all crew members in the loop
Teamwork- call switch movements, both visually identify traffic/airports
Assertion-speak up with questions, doubts or concerns
Operational Issues-low time minimums, DMIs

Clearance

ATIS/NOTAMS
Routing/SID/Terrain
Runway/Taxi conditions
Assign PF/PNF
Plan for abnormal after takeoff
Performance

Approach

Approach plate information
Requires calls/profile
Crew Coordination

Debriefs Items

Deviation from SOP
Crew Coordination- CRM and technical aspects
Unusual situations-positive and negative
Workload management-rushed, overloaded or confusion
Conflicts-differences in expectations
Maintenance discrepancies
Planning for aircraft servicing

<u>APPENDIX D:</u> SPECIFIC CRM SIMULATION SITUATIONS, ALONG WITH CRM ASSESSMENT FORMS IN SIMULATION TRAINING, (Seamster, Boehm-Davis, Holt & Schultz, 1998).

Simulation Situations Given to Pilot Trainees in CRM Training

1- Takeoff- the event trigger is the consideration and ramifications of summer operations, low visibility and wind shear. Other event distracters will include (Conditions for departure include: possibility of wind shear, low visibility taxi, thunderstorms, and turbulence on departure.

2- Takeoff- as the aircraft approaches the end of the runaway for departure. The trigger will be the stop of departures because of thunderstorms. Conditions include: takeoff from contaminated runway near runway limit weight, low visibility taxi, planning for windshear departure, reroute around thunderstorms, different intersection for departure.

Simulator Self Assessment Form

	Doing well	Must do more	Must do less	Other people experi-ence I do	Other people experi-ence I do not do
Communication					
1. Tell others what I mean	_____	_____	_____	_____	_____
2. Talking all the time	_____	_____	_____	_____	_____
3. Impose my own ideas to the others	_____	_____	_____	_____	_____
4. Listen actively	_____	_____	_____	_____	_____
5. Share information	_____	_____	_____	_____	_____
6. Validate information in relation to the task given	_____	_____	_____	_____	_____
7. Ask questions to understand the problem	_____	_____	_____	_____	_____
8. Has no opinion of my own	_____	_____	_____	_____	_____
9. Do not participate in the process	_____	_____	_____	_____	_____
Teamwork					
1. Co-ordinate my activities with the crew.	_____	_____	_____	_____	_____
2. Work towards the objective of the task given	_____	_____	_____	_____	_____
3. Showing flexible behaviour	_____	_____	_____	_____	_____
4. Assertive	_____	_____	_____	_____	_____

Problem solving and
Decision making

1. Analyze problems, suggest alternative solutions, assess the possible outcome of a decision					
2. Decide rapidly on a appropriate action, and carry out immediately					

Leadership

1. Show initiative (advancing the process)					
2. Regulate (suggest changes in the process)					
3. Informative (share actively relevant information)					
4. Supportive (support initiative from the crew)					
5. Evaluate (analyze the problem, suggest alternative solutions, assess the possible outcome of a decision)					
6. Be in command (accept challenges, carry out actions in order to surmount difficulties)					

Stress coping

1. No significant degradation in performance during increased workload					

Resource management

1. Overview (structure the tasks)					

APPENDIX E: EXAMPLE OF NTSB ACCIDENT INVESTIGATION SHEETS (NTSB, 2002).

Error coded in this paper as caused by 'professionals outside the cockpit'

NTSB Identification: **FTW97IA128** . The docket is stored in the (offline) NTSB Imaging System.
Scheduled 14 CFRPart 121 operation of Air Carrier CONTINENTAL AIRLINES
Incident occurred Tuesday, March 18, 1997 at HOUSTON, TX
Aircraft:McDonnell Douglas DC-9-32, registration: N12508
Injuries: 101 Uninjured.

An uncontained failure of the right engine occurred as the airplane lifted off the runway and began its initial takeoff climb. The airplane returned to the departure airport for a single-engine landing, and emergency crews extinguished a fire confined to the right engine's hot section. The uncontained failure resulted from a fatigue crack in the combustion chamber outer case at the forward drain boss weld. Based on an analysis of fatigue striation measurements, a detectable crack existed at the forward drain boss weld when an on wing ultrasonic inspection of the boss was performed by company maintenance personnel in December 1995.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows.

The failure of company maintenance personnel to perform a proper inspection of the combustion chamber outer case, thus allowing a detectable crack to grow to a length at which the case ruptured.

Error coded in this paper as 'not related'

NTSB Identification: **LAX97IA161.** The docket is stored in the (offline) NTSB Imaging System.
Scheduled 14 CFRPart 121 operation of Air Carrier UNITED AIRLINES
Incident occurred Wednesday, April 16, 1997 at RIALTO, CA
Aircraft:Boeing 737-500, registration: N930UA
Injuries: 1 Minor, 99 Uninjured.

The aircraft was on a standard instrument arrival when the captain, who was on the controls, noticed a green light illuminating the aircraft. It appeared to him that the light was tracking the aircraft, but as he pointed out that fact to the first officer, the light disappeared. The captain reported that although the light caused a minimal yet persistent loss of night vision, he was able to maintain control of the aircraft throughout the remainder of the flight. He told ATC that the light appeared to emanate from the western edge of the city. A medical examination by Air Force specialists revealed no permanent evidence of eye damage. Investigators were unable to locate the source of the light. There were no NOTAMs for laser light activity at the time of the incident.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows.

A laser light source of undetermined origin, directed by unknown person(s) toward the cockpit window of the aircraft, while the aircraft was on an approach to land.

Error coded in this paper as 'SOP adherence error '

NTSB Identification: **CHI91LA087** . The docket is stored on NTSB microfiche number **43035.**
Scheduled 14 CFRPart 121 operation of Air Carrier AMERICAN AIRLINES
Accident occurred Friday, January 25, 1991 at INDIANAPOLIS, IN
Aircraft:BOEING 727-200, registration: N815AA
Injuries: 1 Serious, 92 Uninjured.

American flight 323 (aa323) taxied to the hold short line for runway 23r. In an attempt to correct a static/pressurization system problem the crew performed a power run-up. The jet blast contacted and moved a northwest dc9 (nw878) which was parked at gate a7, behind and perpendicular to aa323. The movement of the airplane resulted in an external heater hose disconnecting from the airplane. A 15 lb metal coupling on the end of the hose struck a mechanic when it disconnected. The mechanic was hospitalized with internal injuries. The crew of aa323 reported being unaware of the close proximity of nw878. Aa323 did not request or obtain a clearance to perform the run-up in the unauthorized area.

The national transportation safety board determines the probable cause(s) of this accident as follows.

The pilot's failure to use proper procedures; improper use of the throttles.

Error coded in this paper as 'decision-making error'

NTSB Identification: **ATL91LA091** .
The docket is stored on NTSB microfiche number **44842.**
Scheduled 14 CFRPart 121 operation of Air Carrier USAIR
Accident occurred Saturday, May 04, 1991 at MEMPHIS, TN
Aircraft:BOEING B767-287ER, registration: N651US
Injuries: 1 Serious, 11 Minor, 104 Uninjured.

THE FLIGHT WAS IN LEVEL CRUISE FLIGHT AT FL430. THERE WAS SIGNIFICANT LEVEL 6 THUNDERSTOM ACTIVITY IN THE IMMEDIATE VICINITY OF THE TOLSA VOR AT THE TIME OF THE ACCIDENT, AND SIGMETS HAD BEEN ISSUED TO AND RECEIVED BY THE FLIGHT CREW ADVISING OF THIS ACTIVITY. THE FLIGHT CREW STATED THAT THE ONLY WEATHER BEING DEPICTED BY THEIR ON BOARD WEATHER RADAR WAS 40 MILES FROM THEIR POSITION AT THE TIME OF THE ACCIDENT AND NOT IN THEIR FLIGHT PATH. ACCORDING TO TRANSCRIPTS OF THEIR CONVERSATION WITH AIR TRAFFIC CONTROL PERSONNEL, APPROXIMATELY FIVE MILES WEST OF THE TULSA VOR AND TWO MINUTES PRIOR TO THE ACCIDENT, THE FLIGHT CREW REQUESTED AND RECEIVED PERMISSION TO DEVIATE FROM THE ASSIGNED COURSE IN ORDER TO AVOID BUILDUPS IN THEIR FLIGHT PATH. THE FLIGHT ENCOUNTERED SEVERE TURBULENCE FOR A PERIOD OF ABOUT 10 TO 20 SECONDS. THE AIRCRAFT DESCENDED 3500 FEET BEFORE THE FLIGHT CREW WAS ABLE TO REGAIN CONTROL OF THE AIRCRAFT'S DESCENT. THE FLIGHT THEN DIVERTED TO MEMPHIS, TENNESSEE IN ORDER TO OBGAIN MEDICAL ATTENTION FOR THOSE PERSONS INJURED IN THE CABIN SECTION OF THE AIRCRAFT.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows.

THE DELAYED INFLIGHT DECISION BY THE PILOT TO MANEUVER THE AIRCRAFT AWAY FROM THUNDERSTORM ACTIVITY.

Error coded in this paper as 'crew coordination error'

NTSB Identification: **DEN92IA007** . The docket is stored on NTSB microfiche number **45371.**
Scheduled 14 CFRPart 121 operation of Air Carrier UNITED AIRLINES
Incident occurred Wednesday, October 30, 1991 at COLORADO SPRING, CO
Aircraft:DOUGLAS DC-10-10, registration: N1808U
Injuries: 57 Uninjured.

AS THE AIRCRAFT APPROACHED 50 KIAS ON THE TAKEOFF ROLL, IT DRIFTED RIGHT. THE FIRST OFFICER, WHO WAS MAKING THE TAKEOFF, CORRECTED WITH LEFT RUDDER. RIGHT DRIFT BECAME MORE PRONOUNCED AND HARD LEFT RUDDER WAS USED. THE CAPTAIN TOOK OVER, RETARDED ALL THREE THROTTLES, THEN ATTEMPTED TO REGAIN CONTROL BY USING ASYMMETRICAL THRUST. WHEN THIS FAILED, THE THROTTLES WERE RETARDED AND REVERSE THRUST APPLIED. POST INCIDENT INSPECTION DISCLOSED NO APPARENT DAMAGE. THE NEXT MORNING, A DIFFERENT CREW REJECTED THE TAKEOFF WHEN THE NO. 3 ENGINE FAILED. POST INCIDENT DISASSEMBLY AND INSPECTION OF THE ENGINE DISCLOSED METAL IN THE TAILPIPE, SAND AND MUD IN THE COMPRESSOR SECTION, AND A 13TH STAGE AND TWO 14TH STAGE COMPRESSOR BLADES BROKEN OFF, CAUSING EXTENSIVE DAMAGE TO BOTH THE LOW AND HIGH PRESSURE TURBINES.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows.

THE CAPTAIN'S INADEQUATE SUPERVISION OF THE COPILOT. AND THE COPILOT'S FAILURE TO MAINTAIN DIRECTIONAL CONTROL. FACTORS WERE: THE CROSSWIND AND SNOW/ICE ON THE RUNWAY.

APPENDIX F: AIRLINE PILOT 'HUMAN ERROR' CODING METHODOLOGY

Airline Pilot 'Human Error' Coding Methodology

1. The Purpose

The objective of this work is to identify and code 4 different categories of human error in aviation.

2. The Categories

Note: every error category was carefully defined to all coders and they were all trained on the methodology process. Following the training, all coders were capable of coding the errors in a standard and consistent manner.

Category 1

Pilot "crew coordination" Error:

Failure to build up shared knowledge among crewmembers (not sharing information or necessary knowledge in a particular flight situation).

Lack of problem verbalization (not using standard/similar wording, articulations or expressions while discussing a certain flight condition).

Lack of awareness on the actions of the other crewmember (co-pilot acting without the knowledge of the pilot or vise versa).

Misinterpretation of information between crewmembers (here the crew have used the right wording and articulation in their conversation, and they have shared necessary information, though, the manner in which the conversation was conducted was misleading and hence caused a misunderstanding).

Failure to defy incorrect decisions or actions; in this case the flight crewmembers are discussing a particular situation and the pilot is making wrong judgments while the co-pilot fails to challenge those erroneous conclusions (Here, the factor behind the accident/incident should be the co-pilot not defying the pilot's judgment WHILE discussing a particular situation and NOT after the pilot has taken the decision and acted upon that).

Category 2

Pilot "decision-making" Error:

Failure to make the right decision under pressure (aircraft major/minor technical dysfunction, and/or major/minor weather condition).

Failure to make the correct decision due to a lack of experience in that particular condition (in this case the factor behind the accident/incident should be pilot erroneous decision and the contributing factor to the accident/incident should be: lack of crewmember experience in this particular situation).

Premature/impulsive decision by the pilot (failure to verify aircraft data output / or aircraft manuals while taking a decision).

Making a careless decision under routine/normal flight conditions.

Category 3

Pilot "Standard Operating Procedure adherence" Error:

Failure to refer to a particular SOP.

Failure to follow SOPs in assigned order.

Erroneous interpretation of an SOP under normal conditions.

Erroneous interpretation of an SOP under abnormal conditions.

Infringe / contradict SOPs under normal conditions.

Infringe / contradict SOPs under abnormal conditions.

Category 4

Error of professionals outside the cockpit: *these are defined as the errors committed by airline professionals outside the cockpit (error of mechanics, flight attendants, aircraft inspectors, or company management).*

3. The Sample

The sample used in this coding effort comprises all CFR part 121 aircraft accidents encountered in the United Sates between 1990 and 1999.

4. The Methodology

1. **Build up an Excel spreadsheet similar to the table underneath.**

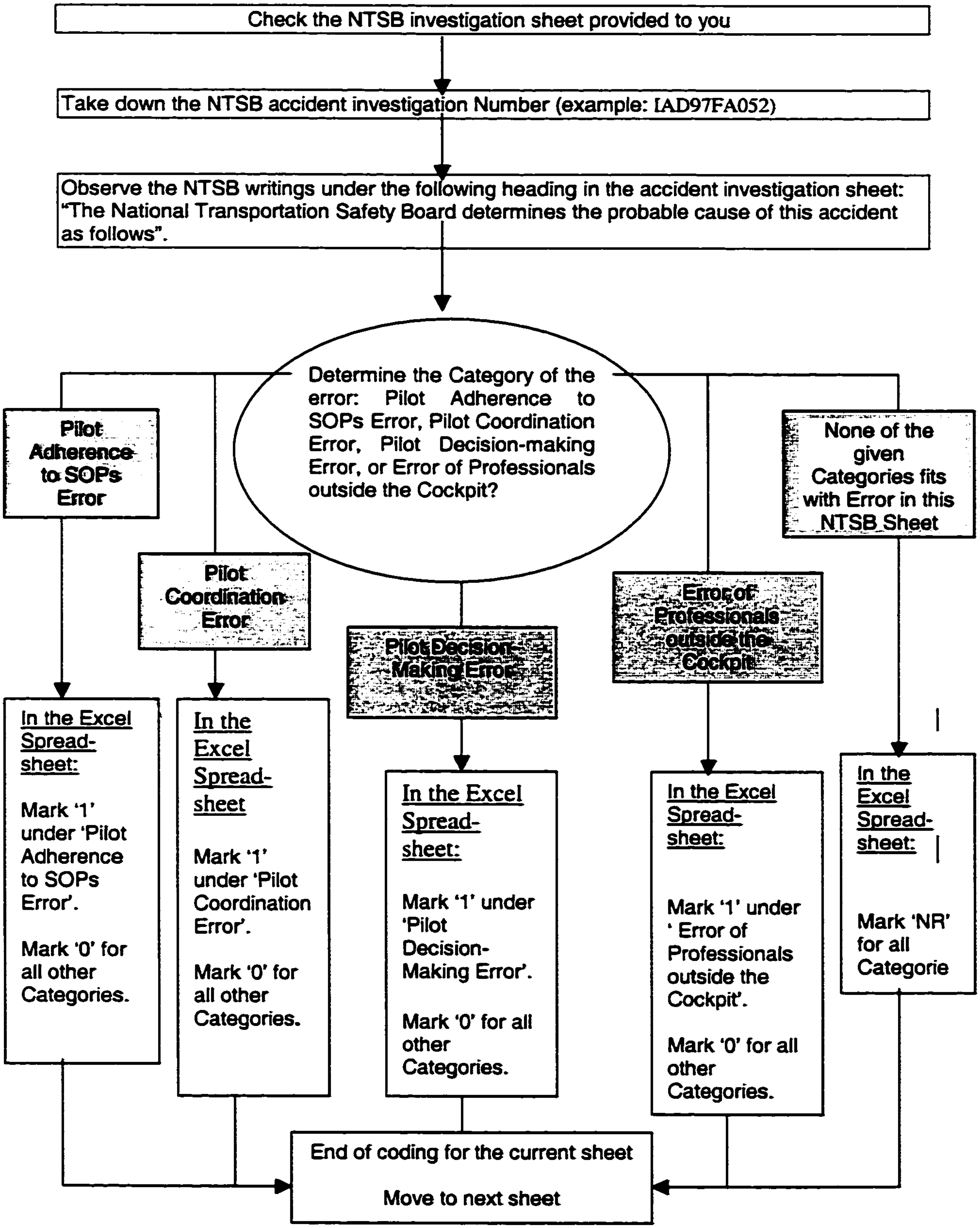
NTSB ID Number	Pilot adherence to SOPs Error	Pilot Coordination Error	Pilot decision-making Error	Error of Professionals outside the Cockpit
IAD97FA052	*0*	*1*	*0*	*0*

Model on how to fill in the table (see procedure).

2. **Follow the procedure on page 4 to fill up the above table.**

Note 1:Follow the procedure below for each and every NTSB investigation sheet provided to you.

Note 2: A model showing the end result of this procedure for *one* sheet is given in the above table.


Check the NTSB investigation sheet provided to you
Take down the NTSB accident investigation Number (example: IAD97FA052)
Observe the NTSB writings under the following heading in the accident investigation sheet: "The National Transportation Safety Board determines the probable cause of this accident as follows".
Determine the Category of the error: Pilot Adherence to SOPs Error, Pilot Coordination Error, Pilot Decision-making Error, or Error of Professionals outside the Cockpit?
Pilot Adherence to SOPs Error
Pilot Coordination Error
Pilot Decision-Making Error
Error of Professionals outside the Cockpit
None of the given Categories fits with Error in this NTSB Sheet
In the Excel Spread-sheet: Mark '1' under 'Pilot Adherence to SOPs Error'. Mark '0' for all other Categories.
In the Excel Spread-sheet Mark '1' under 'Pilot Coordination Error'. Mark '0' for all other Categories.
In the Excel Spread-sheet: Mark '1' under 'Pilot Decision-Making Error'. Mark '0' for all other Categories.
In the Excel Spread-sheet: Mark '1' under ' Error of Professionals outside the Cockpit'. Mark '0' for all other Categories.
In the Excel Spread-sheet: Mark 'NR' for all Categorie
End of coding for the current sheet
Move to next sheet

APPENDIX G: NTSB ACCIDENTS RATES 1982 THROUGH 2000, FOR U.S. AIR CARRIERS OPERATING UNDER 14 CFR 121, SCHEDULED AND NONSCHEDULED SERVICE (NTSB, 2001).

	Accidents		*Fatalities*			
Year	*All*	*Fatal*	*Total*	*Aboard*	*Flight Hours*	*Miles Flown*
1982	18	5	235	223	7,040,325	2,938,513,000
1983	23	4	15	14	7,298,799	3,069,318,000
1984	16	1	4	4	8,165,124	3,428,063,000
1985	21	7	526	525	8,709,894	3,631,017,000
1986	24	3	8	7	9,976,104	4,017,626,000
1987	34	5	232	230	10,645,192	4,360,521,000
1988	30	3	285	274	11,140,548	4,503,426,000
1989	28	11	278	276	11,274,543	4,605,083,000
1990	24	6	39	12	12,150,116	4,947,832,000
1991	26	4	62	49	11,780,610	4,824,824,000
1992	18	4	33	31	12,359,715	5,039,435,000
1993	23	1	1	0	12,706,206	5,249,469,000
1994	23	4	239	237	13,124,315	5,478,118,000
1995	36	3	168	162	13,505,257	5,654,069,000
1996	37	5	380	350	13,746,112	5,873,108,000
1997	49	4	8	6	15,838,109	6,691,693,000
1998	50	1	1	0	16,821,641	6,741,691,000
1999	52	2	12	11	17,381,999	7,032,971,000
2000	54	3	92	92	18,040,000	7,134,600,000